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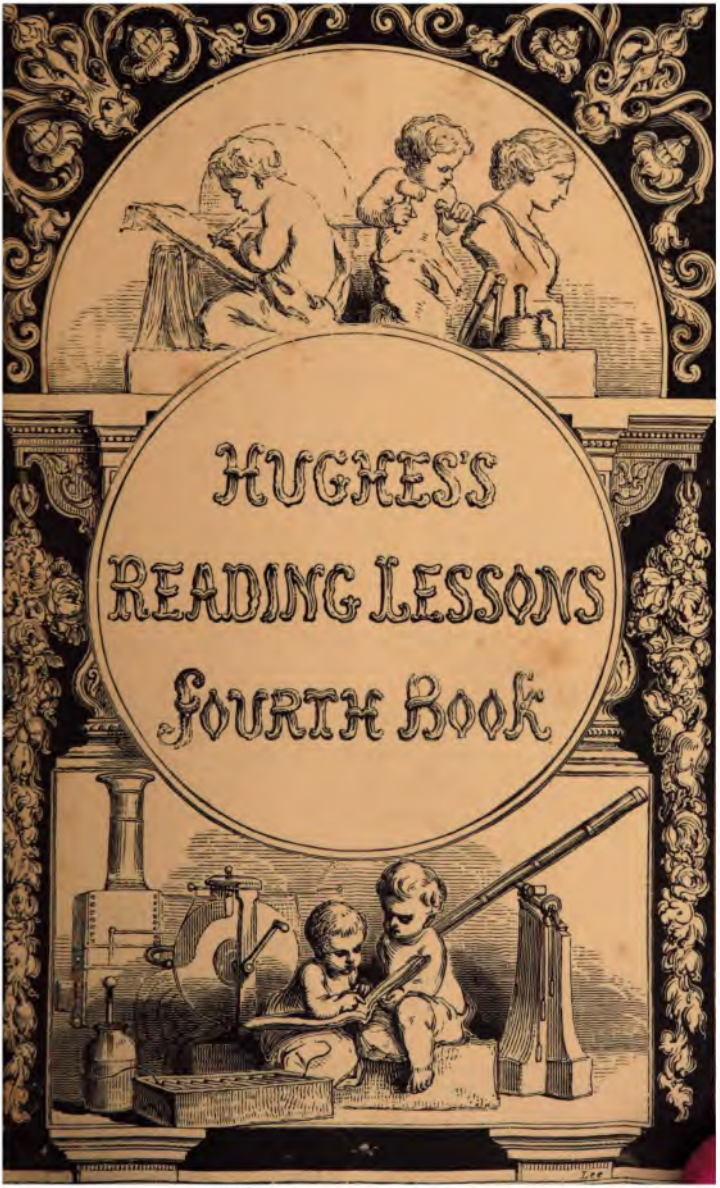
HUGHES'S
READING LESSONS
FOURTH BOOK

READING LESSONS.

ADVANCED SERIES.

FOURTH BOOK.

EDITED BY

EDWARD HUGHES,

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ASSOCIATE OF THE INSTITUTION OF CIVIL ENGINEERS;

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With Numerous Illustrations.

"No doubt the sovereignty of man lieth in knowledge; wherein many things are reserved, which kings with their treasure cannot buy, nor with their force command; their spials and intelligencers can give no news of them, their seamen and discoverers cannot sail where they grow."—BACON.

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PREFACE.

As three Volumes of this series of *Reading Lessons* have been now, for some time, in the hands of teachers, families, and private students, and have received the most gratifying marks of approval, the Editor deems it unnecessary, in publishing the Fourth Book, to do more than assure his readers, that no care has been spared to make it, if possible, better than its predecessors.

The table of contents exhibits the very interesting nature of the subjects treated of in this Volume, and a glance at the pages will show the increased abundance of illustrations.

In the various departments of Natural Philosophy, Biography, Manufactures, and the Fine Arts, will be found a number of carefully-written articles, containing the most recent as well as most accurate information on the subjects of which they treat. In clearness of explanation, and general adaptation to the purposes of sound education, the closest attention has been paid to practical utility, both by the Editor and the gentlemen to whose labours he is so much indebted.

E. H.

ROYAL NAVAL SCHOOLS,
GREENWICH HOSPITAL,
May, 1858.

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READING LESSONS.

FOURTH BOOK.

Meteorology.

BY JAMES GLAISHER.

LESSON I.

THE BAROMETER.

"And God made the firmament, and divided the waters which were under the firmament from the waters which were above the firmament."

1. METEOROLOGY* is that part of Natural Philosophy which treats of the various phenomena which have their origin in the atmosphere. With the view of connecting cause and effect, and determining the laws by which atmospheric changes are regulated, its pursuit embraces investigations into the degrees of atmospheric pressure, temperature, humidity, purity of air, and its admixture with exhalations more or less salubrious; the course of storms, clouds, clearness of sky, meteors; the fall of rain, hail, snow, and all other phenomena and modifications of the atmosphere, by which our organs are affected.

2. The volume of the atmosphere is composed of permanently-elastic fluids, which are retained near the surface of the earth by gravitation. Its main constituents are the gases oxygen and hydrogen. The atmosphere also contains a certain amount of moisture, carbonic acid, and minute portions of vapours of all substances with which it is in contact, some of which are of too subtle a nature or in too small quantities to

* For Tables and Authorities see Appendix, pp. 442–54.

be detected by our instruments. Some of these unknown substances, when mingled with the atmosphere, impart to it deleterious qualities. By experiment it has been found that the proportions of oxygen and hydrogen are very uniform at all places on the earth, at all heights above its surface, and at all seasons of the year, and amount to 77 parts nitrogen, 23 oxygen by weight—79 parts nitrogen, 21 oxygen by volume. The component in the atmosphere which is liable to the greatest change in its quantity is the amount of moisture, and including this and carbonic acid at an average temperature and pressure, the ordinary constituents of the atmosphere appear to be in the following proportions:—

Oxygen - - - -	19·7
Nitrogen - - -	78·8
Aqueous vapour - -	1·4
Carbonic acid - - -	0·1
	100·0

3. These several elastic fluids constituting the atmosphere do not separate or arrange themselves according to their relative specific gravities, and therefore form independent atmospheres mixed together, but not in a state of combination. Each of its ingredients exerts its own separate pressure to make up the whole pressure of the atmosphere, and when the reading of the barometer is 30 inches, the part due to each is nearly as follows:—

The elastic force of nitrogen - -	23·4 inches.
,, ,, oxygen - -	6·2
,, ,, vapour - -	0·4
	30·0

The pressure due to the presence of carbonic acid gas amounts to 0·02 inch only; and of ammonia there is only a trace.

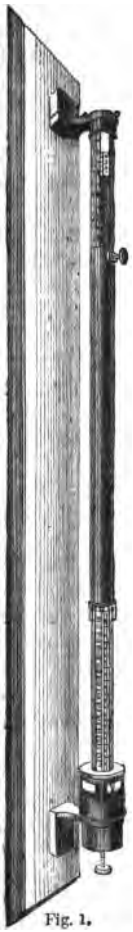
4. Weight of the air.—If a glass tube, three feet in length, and closed at one end, be filled with mercury, and its open end plunged in a basin filled with

the same metal, the surface of the mercury in the tube will be, at the level of the sea, nearly 30 inches higher than that in the basin. This column of mercury is balanced by a column of air, of the same area as that of the tube, and extending to the top of the atmosphere; if that of the tube be one inch, the mercury in the tube weighs nearly 15 pounds, therefore the atmosphere presses on the surface of the earth with a weight of 15 pounds to the square inch, when the reading of the barometer is 30 inches.

5. The atmosphere is influenced by a multitude of causes, and is ever varying in pressure, temperature, humidity, &c. The barometer is one of the instruments employed to determine these incessant changes, and has rendered very essential service to science. It has determined that the pressure of the atmosphere at the level of the sea supports a column of mercury from 29 to 30 inches in length all over the world, and that as we ascend, the pressure decreases. Approximate laws have been determined connecting the pressure of the higher with that of the lower strata of the air, and these have had an important bearing in relation to physical geography in making known to us the various irregularities of the earth's surface, determining the elevation of the sources of rivers and the sites of ancient cities, the heights of mountains, &c. It is in daily use in determining, in astronomical observations, the amount of atmospheric refraction; on board ship in indicating the approach of storms; and, connected with the changing direction of the wind in storms, points the way to sail out of them.

6. Thus the barometer holds an intimate connexion with the pressure of the air, and its distribution over the varied surface of the earth. Its value, however, is greatly dependent upon the method of its construction. In the making, all air and moisture should be excluded from the tube, and the mercury with which it is intended to be filled should be pure and boiled within it: the diameter of the tube should be such that the correction

for capillarity be small, as in such a tube the mercury moves with greater freedom, and the variation follows with more promptness than in one of small diameter. Its readings before use should be compared with those of a standard barometer, for the purpose of determining its index error. In use corrections should be applied for index error, and capillarity of tube, and for the reduction of the observations to what they would have been at a constant temperature.



STANDARD BAROMETER.

Fig. 1.

7. The annexed engraving (fig. 1) shows the form of instrument in general use among the members of the British Meteorological Society. It consists of a tube from three to four-tenths of an inch in its inner diameter, filled with pure mercury, of 13·5 specific gravity,* and which has been boiled within it throughout its whole length. The open end of the tube is immersed in a cistern of pure mercury, and the whole enclosed in a brass cylinder or tube. A piece of ivory or steel is fixed to the upper part of the cistern, pointing downward: the image of this is reflected from the surface of the mercury in the cistern, which is raised or lowered *at every observation*, till the ivory point

* As the lengths of liquid columns balanced by the atmosphere are inversely as their densities, it is imperatively necessary to employ pure mercury, and of the same specific gravity, or otherwise the length of the column will be longer than that shown by a standard barometer.[1]

[1] Mercury is purified from the presence of lead or iron by washing it with acetic or sulphuric acid.

and its image are just in contact. This ivory point forms one end of the scale. The upper part of the brass tube is graduated into inches, and parts of inches, reckoning from the ivory point in the cistern, and constitutes the scale. A thermometer is attached to the barometer, with its bulb immersed in the mercury in the cistern, or, if the instrument is intended for travelling, it is affixed to the tube, its bulb being of the same size as the tube of the barometer. The whole is attached to a slab of mahogany, which may be secured at will against a wall or wooden frame.

8. We will now suppose the observer in possession of his barometer: he is desirous to ascertain that it is in good working order: he must, for that purpose, determine whether the space above the mercury be free from air. This is done by inclining the instrument from its vertical position, when, if the mercury, in striking against the upper end of the tube elicit a sharp tap, the perfect condition of the vacuum is fully established. If the tap be dull or not heard at all, the amount of air above the mercury is considerable, and must be driven into the cistern by inverting the instrument, and gently tapping it with the hand. If the confined air cannot be thus expelled, the instrument is useless.

Having satisfactorily determined that there is no air within the tube, it is necessary to fix the barometer in a suitable position. For this purpose a place should be chosen, commanding a good light, but not exposed to sunshine; and the tube adjusted vertically or nearly so, by means of a plumb-line, and fixed by means of the three screws, either situated at the top or at the bottom of the tube.

9. In observing, the eye should be placed, by means of the fore and back part of the lower termination of the vernier, at an exact level, and whilst so placed, the lower part of the vernier should be brought to the apex of the mercurial column,—so that the eye, the fore part of the vernier, the top of the mercurial column, and the back of the vernier, be all in the same horizontal plane.

The reading is to be taken by means of the scale on the limb and the vernier. It is necessary, however, to explain the vernier and its action.

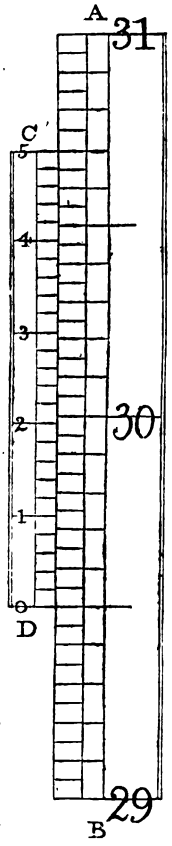


Fig. 2.

10. *The vernier* is a contrivance (invented by Peter Vernier, who published an account of it, in a work printed at Brussels in 1631) for measuring small spaces between the divisions of the graduated limb of an instrument. It consists of a short moveable scale, made to pass along the graduated limb, the divisions of the one being to those of the other in the proportion of two numbers, which differ from each other by unity. The vernier is moved by either a micrometer-screw, or, as applied to the barometer, by a rack and pinion, and slides up and down the principal division on the instrument.

When the vernier is so placed that its zero coincides exactly with a division on the limb, the reading is made at once from the limb, and the vernier is not brought further into use; but, if the zero of the vernier does not coincide with any division on the limb, but falls between two of them, which is usually the case, then some other division of the vernier will coincide, or very nearly coincide, with one of the divisions on the limb, and the reading on the limb at the zero of the vernier is to be increased by the reading of the vernier.

11. The scale of the barometer is divided into inches, reckoning from the surface of the mercury in the cistern: each inch

is divided into ten parts, or into tenths of inches; and each tenth of an inch is further divided into half-tenths, or five-hundredths of an inch. The vernier is made equal in length to twenty-four of these divisions, and divided into twenty-five equal parts; consequently one of the smaller divisions on the barometer-scale is divided into as many parts as there are divisions on the vernier. In this case, each division on the scale is 0·05 inch, which divided into twenty-five parts gives 0·002 inch, so that a vernier thus arranged reads to two-thousandths of an inch. In practice it will at times happen that no line on the vernier is in coincidence with a line on the scale: in these cases the reading is intermediate, and may be taken to a thousandth of an inch.

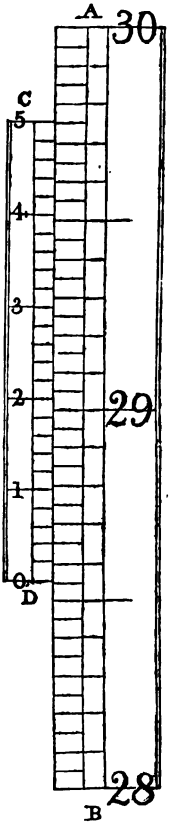


Fig. 3.

12. An example will make this description (necessarily complicated) easy. Let A B (fig. 2) be the scale of the barometer, divided into inches, tenths, and five-hundredths of an inch.

Let C D be the vernier, equal in length to twenty-four of the smallest divisions on the limb, and divided into twenty-five equal parts.

Let the position of the vernier with respect to the scale be as represented in the diagram, where its zero is coincident with the line 29·5 inches on the scale, the reading in this case would be 29·500 inches. If the zero of the vernier coincided with any other division on the scale, the reading of that division would be the one required.

13. Suppose, on the contrary, that the position of the

vernier with respect to the scale be such, that its zero does not coincide with any division on the limb, then by passing the eye along the vernier, some other division will be found coincident, or nearly coincident, with a line on the scale.

Let A B (fig. 3) be the barometer-scale as before, and C D the vernier, the zero of which is situated between the readings of 28·5 and 28·6 on the scale, therefore the reading is greater than 28·50, but less than 28·60. The reading 28·5 is at once taken, the zero is above the half-tenth or five-hundredth, making therefore 28·55. The reading is 28·55, and the space between the zero of the vernier and the line 28·55: *this space is measured by the vernier.*

14. The vernier is divided into five great divisions, marked 0, 1, 2, 3, 4, 5, corresponding to the hundredths of an inch: by passing the eye up the vernier, if the line marked 3 on it be found coincident with 1 on the limb, it shows that the zero line of the vernier is three-hundredths of an inch above the division the next below it on the scale, and the reading would be 28·58. In like manner, had the line marked 1, 2, or 4, been coincident, the reading would be found in the same way. It may happen, however, that not one of these lines is coincident, but one which is situated between two of them. The space between two consecutive numbers on the vernier is divided into five equal parts; that is, one-hundredth of an inch is divided into five equal parts, so that the small division on the vernier corresponds to $\frac{0{\cdot}01}{5} = 0{\cdot}002$ inch (two-thousandths of an inch). If, therefore, the first line on the vernier above 3 had been coincident in the last example instead of the line 3, the reading would have been 28·582; if the second line above had been coincident, the reading would have been 28·584, and so on.

In fig. 3 the second line from the zero of the vernier is coincident with a line on the scale, and as each of the small divisions on the vernier corresponds to 0·002

inch, the space between the zero of the scale and the line 28·55 on the limb is 0·004 inch, and the reading of fig. 3 is 28·554 inch.

The reading of the thermometer attached to the barometer must be taken with every observation of the barometer.

15. *Corrections to be applied to barometer-readings* are three in number—viz., one for the depression of the mercury in the tube, owing to capillarity; the second for index-error: these two corrections are constant for the same instrument, and may be combined by taking their algebraical sum, applied as one correction. The corrections for capillarity for boiled-tubes of different diameters are as follows:—

Diameter of tube.	Corrections for capillarity.
0·1 inch	0·070 inch
0·2 ,,	0·029 ,,
0·3 ,,	0·014 ,,
0·4 ,,	0·007 ,,
0·5 ,,	0·003 ,,
0·6 ,,	0·002 ,,

These numbers in all cases are to be applied additively. As the corrections are considerable, and some uncertainty exists when the diameter is small, tubes of less than 0·3 inch should not be used. The index-error is the difference between the true readings and those given by the barometer, and is determined by means of a standard barometer, or by one whose error of graduation is known. If the barometer reads too high, the correction for index-error is subtractive; and if too low, additive.

16. As both the mercury and the tube expand and contract with an increase or decrease of heat, the readings of a barometer will vary with the differences of temperature, although the atmospheric pressure may continue unaltered; it is therefore necessary to apply corrections on this account, and also for the purpose of comparing together observations, taken at distant places, where the temperatures are necessarily different.

17. *Example.*—Suppose the reading of a barometer —whose inner diameter of tube is 0·3 inch, and index-error is + 0·005 inch—to be 29·785, and that of the attached thermometer to be 75°, required the correct reading of the barometer at the temperature of 32°.

Reading of the barometer	29·785	attached therm. 75°
Correction for capillarity	+ ·014	
	29·799	
Correction for index-error	− ·005	
	29·794	
Correction for temperature	− ·124	
Correct reading at 32°	29·670	

Had the reading of the attached thermometer been 20° instead of 75°, the reduction would have been performed as follows:—

	Inches.
Barometer-reading corrected for index-error and capillarity	29·794
Corrections for temperature to 32°	+ ·023
Correct reading at 32°	29·817

18. The readings of the barometer are almost constantly varying; the daily changes in a year are as follows:—

	Inches.		Inches.
On 132 days the change is		less than	0·1
On 123 days it exceeds	0·1	and is less than	0·2
On 61 ,, ,,	0·2	,, ,,	0·3
On 27 ,, ,,	0·3	,, ,,	0·4
On 12 ,, ,,	0·4	,, ,,	0·5
On 6 ,, ,,	0·5	,, ,,	0·6
On 4 ,, ,,	0·6	,, ,,	1·0

and on one day in ten years the variations may amount to 1¼ inch.

19. The average daily change of reading in the months of

	Inches.
March, April, and May, is	0·165
June, July, and August, is	0·139
September, October, and November, is	0·190
December, January, and February, is	0·213

Upon the whole year the average is 0·175 inch.

The range of reading in each month is shown in the following table:—

Month.	Range of Readings of Barometer.	Month.	Range of Readings of Barometer.
	Inches.		Inches.
January -	1·44	July - -	0·79
February -	1·22	August -	0·97
March - -	1·23	September -	0·95
April - -	1·06	October -	1·33
May - -	1·02	November -	1·53
June - -	0·89	December -	1·52

In summer the range may be as small as 0·5 inch, and in winter as large as 2·5 inch.

20. In the torrid zone the daily oscillations of the readings of the barometer are so uniform that the hour of the day may almost be known from them: even in the temperate zones, where the constant variations from heat to cold, from fine weather to bad, changes in the direction of the wind, &c., seem to impress uncertainty over all, yet, from series of observations extended over a sufficient length of time, with good instruments, analogous changes are shown.

21. In England four times a-day the reading of the barometer is at its mean value (see fig. 4, p. 13): the times in the several months are as follows:—

	h.m.	h.m.	h.m.
In Jan. at midnight;	8·0 a.m.;	0·40 p.m.;	and 5·0 p.m.
In Feb. at midnight;	8·0 a.m.;	1·40 p.m.;	and 6·20 p.m.
In Mar. at midnight;	7·35 a.m.;	1·50 p.m.;	and 6·0 p.m.
In April at 1·0 a.m.;	6·40 a.m.;	1·40 p.m.;	and 7·20 p.m.
In May at 1·0 a.m.;	8·20 a.m.;	1·0 p.m.;	and 8·0 p.m.
In June at midnight;	4·20 a.m.;	1·40 p.m.;	and 9·20 p.m.
In July at 1·0 a.m.;	6·25 a.m.;	1·40 p.m.;	and 8·45 p.m.
In Aug. at 1·0 a.m.;	7·0 a.m.;	1·10 p.m.;	and 7·35 p.m.
In Sep. at 1·0 a.m.;	7·30 a.m.;	1·0 p.m.;	and 7·0 p.m.
In Oct. at 0·25 a.m.;	7·50 a.m.;	1·10 p.m.;	and 5·0 p.m.
In Nov. at 1·40 a.m.;	8·20 a.m.;	11·40 p.m.;	and 5·45 p.m.
In Dec. at 0·40 a.m.;	7·40 a.m.;	0·45 p.m.;	and 6·5 p.m.

It is evident that the diurnal oscillations of the readings of the barometer are different at the different seasons of the year; the season, therefore, exercises an influence over the diurnal oscillation. This circumstance is sufficient to prevent us from being able to determine the mean reading by taking observations at any fixed time throughout the year, for the morning mean, and at any fixed time for the evening mean. That mean reading takes place with the greatest regularity, which occurs between noon and 2 h. P.M.

The diagram in fig. 4 shows that there are two maxima and two minima daily in the readings of the barometer; and throughout the world there are two daily atmospheric tides, the pressure of the atmosphere being greatest about 10 h., both A.M. and P.M., and least in the early morning and afternoon hours.

22. As we can deduce the mean temperature of the air from a few daily observations, to be spoken of presently, so also can we deduce the mean reading of the barometer from a few readings taken daily; and if this be the only element of investigation, that time or times most convenient to the observer may be chosen; but if, in addition, such observations be needed as will serve for studying the irregular oscillations of the readings of the barometer, then several observations must be taken.

When the barometer is to be taken down for removal, the first thing to be done is to remove the thermometer, if its bulb be immersed in the mercury, and to insert the plug; next, by means of the finger-screw at the bottom, to drive the mercury up the barometer tube till it nearly reaches the top: the instrument is then to be taken down, and turned gently over, and carried with the cistern uppermost.

DIURNAL CURVES OF THE READING OF THE BAROMETER IN EVERY MONTH AT GREENWICH.

Scale 0·1 inch to an inch.

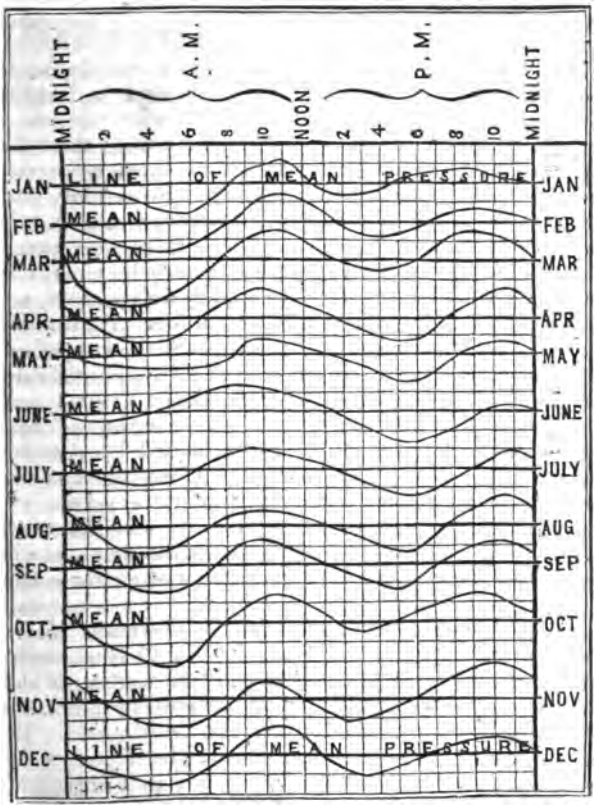


Fig. 4.

LESSON II.

TEMPERATURE OF THE AIR.

"In the day the drought consumed me and the frost by night."

1. The thermometer is an instrument employed to determine the temperature of the air, and is familiar to every one. The principle of its construction is founded upon the expansion of bodies under the influence of heat, and mercury, as expanding more uniformly under equal increments of heat than any other fluid within the range of atmospheric temperature, is mostly employed in its construction. The qualities necessary for a good thermometer are, that the bore be even, that the zero points on the tube be accurately determined, and the graduations performed with exactitude. Before use, every instrument should be compared with a standard, to see whether these conditions are fulfilled, and if not the amount of error should be ascertained.

2. The graduation in use in England is that of Fahrenheit, the scale of which is determined by dividing the space between the point 32° (freezing point of water) and 212° (boiling point of water) into 180 parts, called degrees. By continuing the divisions both above and below these points, the scale may be continued at pleasure, for the requirements of extreme temperatures.

3. The graduation in use by the Germans is that of Reaumur; by the French, that of Celsius, called the Centigrade. The freezing point of water on both these scales is numbered 0°, and the boiling points are 80° by Reaumur, and 100° by the Centigrade. The number of degrees included between the freezing and boiling points of water, therefore, are in Fahrenheit's scale 180°; in Reaumur's 80°; and the Centigrade 100°. So that 9° of Fahrenheit, are equal to 4° of Reaumur, and 5° of Centigrade.

4. The following are the rules for the conversion of any reading on one of these scales into its equivalent reading on another:—

To reduce Fahrenheit's scale to Reaumur's, when the reading is above 32°.—Take 32° from the reading, multiply the difference by 4, and divide the product by 9.

To reduce Fahrenheit's scale to Reaumur's, when the reading is below 32°.—Take the reading from 32°, multiply the difference by 4, divide the product by 9, and affix the minus sign (−).

To reduce Reaumur's scale to that of Fahrenheit, when the reading is above the freezing point.—Multiply the reading by 9, divide the product by 4, and add 32° to the quotient.

To reduce Reaumur's scale to that of Fahrenheit, when the reading is below the freezing point.—Multiply the reading by 9, divide the product by 4, and take the quotient from 32°.

To reduce Fahrenheit's reading to Centigrade, when the reading is above freezing point.—Take 32° from the reading, multiply the difference by 5, and divide the product by 9.

To reduce Fahrenheit's reading to Centigrade, when the reading is below the freezing point.—Take the reading from 32°, multiply the difference by 5, divide the product by 9, and affix the minus sign (−).

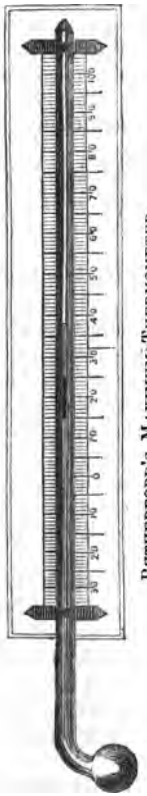
To convert the readings of the Centigrade scale into those of Fahrenheit.—Proceed exactly as in the case of Reaumur into Fahrenheit, except using 5 instead of 4.

To reduce Reaumur's scale to that of the Centigrade.—Multiply by 5, and divide the product by 4.

To reduce the Centigrade scale to that of Reaumur.—Multiply the reading by 4, and divide the product by 5.

As the French tables and observations of temperature are those which most frequently come under our notice, it is desirable that a simple mental calculation should suffice. The following rule is one to convert, in a moment, all readings of the Centigrade

scale into their equivalent values in Fahrenheit's scale; viz., double the Centigrade degrees, and deduct one-tenth of the product, adding 32° if the temperature is above the freezing point, or subtracting the product from 32° if below.



RUTHERFORD'S MAXIMUM THERMOMETER.

Fig. 5.

5. The thermometers in use in a series of meteorological observations, consist of the following:—

A maximum thermometer, for determining the highest temperature of the air.

A minimum thermometer, for determining the lowest temperature of the air.

A maximum thermometer, for solar radiation.

A minimum thermometer, for terrestrial radiation.

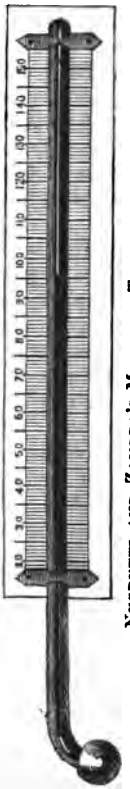
A dry- and wet-bulb thermometer, for hygrometrical results.

A maximum and a minimum thermometer with moistened bulb, for determining the maxima and minima temperatures of evaporation.

I will speak of these instruments successively.

6. *The self-registering maximum thermometer* is used, as its name implies, to determine the maximum or highest temperature of the air. That of Rutherford (fig. 5), till lately, was in general use; it differs from the ordinary thermometer, chiefly in the introduction of a steel index within the tube, which, being adjusted to the end of the mercurial column, slides along, as the increasing temperature of the air causes an expansion of the mercury within. It follows, then, that the index so propelled remains at the highest point of

expansion, and thus records the maximum temperature of the day. On the decline of temperature, the mercury is withdrawn from contact, the index remains, and that end nearest the bulb which was in contact with the mercury, being read upon the division of the scale, gives the required maximum temperature. In use, the instrument is suspended nearly horizontally, its bulb being a little raised. One end of the instrument should be moveable, so as to be readily detached for the purpose of setting the index after reading; which is done by inclining the instrument with its bulb downward, so as to allow the index to pass at once from its last reading to the end of the mercurial column; having done this, the thermometer is again replaced, and is in order for the next day's observation.



NEGRETTI AND ZAMBRA'S MAXIMUM THERMOMETER.

Fig. 6.

In practice, this instrument is subject to frequent derangement, by the tendency of the steel index to become fixed in the tube, either by its plunging into the mercury or by its oxidation, and allowing the mercury to pass, instead of being carried forward by it, thus rendering the instrument useless. For the upper part of the tube of this thermometer is required to be full of air, to prevent the mercury moving about in the tube; and as the mercury passes the index, on one side small particles of air insinuate themselves into the column and cause separations, which require an instrument-maker to correct.

7. A maximum thermometer, invented by Professor Phillips, is better in its action than Rutherford's: a part of the mercurial column is separated by the introduc-

tion of a small portion of air; this portion acts as an index, and remains in the tube at the highest temperature, thus marking the maximum temperature; but, in practice, as I have found many times in the last twenty years, the air soon escapes, and the instrument is reduced to a simple thermometer; and again, whilst in use, the portion of air assumes a different length, at different temperatures, and the index-error is variable. Instruments of this construction have been tried, both by myself and the Members of the Council of the British Meteorological Society, and although they have acted with tolerable accuracy for a time, they have all ultimately failed.

8. A necessity therefore continued to exist for another form of instrument free from these inconveniences. This has lately been produced by Messrs. Negretti and Zambra. The annexed engraving (fig. 6) shows the form of the instrument invented by them. In its construction, whilst the tube is straight, a small piece of glass, which nearly fills the bore, is inserted, and dropped to a place situated near the bulb, and the tube bent at this part, so that the piece of glass cannot move. On an increase of heat, the mercury is forced, in its expansion, past this obstruction, but cannot repass on a decrease of temperature: the contraction of the mercury takes place within the space below the bend of tube. The end of the column of mercury, therefore, gives the required reading. The instrument, after observation, is set by raising the end the farthest from the bulb, and shaking it a little; it is easily set, and scarcely liable to derangement, either in travelling or in use. The tube is free from air.

This instrument is to be read daily, either in the morning or evening; if at the latter time, the reading will be that of the day; but if in the morning, the reading is that of the day before, and must be so entered.

9. The following table shows the most probable highest temperature in each month in the suburbs of London:—

Month.	Highest Temperature.	Month.	Highest Temperature.
	°		°
January -	50	July - -	85
February -	54	August -	83
March -	62	September -	78
April - -	70	October -	67
May - -	77	November -	60
June - -	84	December -	54

In extreme cases the temperature in January may rise to 55°; in February to 60°; in March to 67°; in April to 77°; in May to 86°; in June, July, and August exceeding 90°; in September 86°; October 73°; November 66°, and December 60°.

The Table 2 in the Appendix (page 443) shows the monthly mean of the highest daily temperature of each day, for a series of years, and in fig. 7, the average highest temperature of the air by day is shown.

YEARLY CURVES OF AVERAGE HIGHEST TEMPERATURE BY DAY AND LOWEST BY NIGHT.

Scale 20° to one inch.

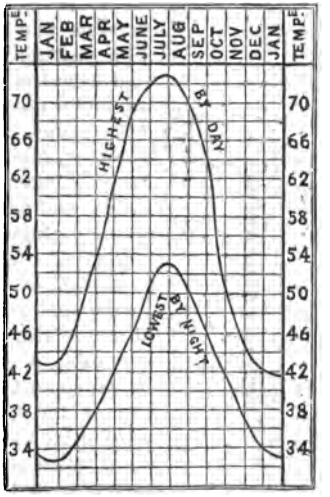


Fig. 7.

10. *The minimum thermometer* for recording the lowest temperature of the air is constructed up to the present time, with alcohol, within which floats a glass index. Alcohol, however, does not expand equally with equal increments of heat, and tubes of instruments so filled are for this reason

not of even bore. The instrument in use is suspended with its bulb a little depressed and its index set to the end of the spirit column, when on a decrease of temperature, the fluid contracts, and carries the index in its descent towards the bulb: this remains at the lowest point of temperature, thus registering the minimum temperature as required. The observer should take care to read on the scale, the position of *that end of the index the farthest removed from the bulb*, and in re-setting to either raise the bulb, or depress the other end till the index is at the extremity of the spirit column. On an increase of temperature the index remains fixed as the alcohol expands. The instrument is not fitted for delicate thermometric purposes, and a mercurial minimum thermometer has long been a desideratum. Within the last few weeks, however, Messrs. Negretti and Zambra have invented one, which, so far as I have examined and tried, answers well; its form is shown in the annexed engraving. It is made as follows:—

Fig. 8.

NEGRETTI AND ZAMBRA'S MERCURIAL MINIMUM THERMOMETER.

Having blown, filled, and regulated a thermometer-tube in the usual way, 60° of temperature being about half-way in the tube, a small cylindrical bulb is blown about two inches from the upper end of the thermometer, into which is introduced a steel needle pointed at both ends, rather abruptly at that nearest the mercury, and terminating in a long conical point at the upper end. The portion of the thermometer-tube above the smaller bulb is now drawn into a fine capillary-tube, and the bulb of the instrument warmed sufficiently to raise the mercury

into the smaller bulb completely covering the needle: this bulb being full, the warming is continued until the mercury passes the capillary-tube; at this moment, and before the mercury has time to return, the flame of a blowpipe lamp is applied, which melts the glass, and enables the operator to draw off a small portion of it containing mercury, thus effectually cutting off all communication with the external atmosphere. As the temperature decreases, the mercury will descend and indicate the surrounding temperature. If, whilst cooling, the thermometer be held upright, as the last portion of mercury leaves the bulb, the steel index will, of its own gravity, follow. The thermometer, in appearance, is very similar to Rutherford's maximum, viz., a tube of mercury with a steel index floating on its surface, but with these important differences: the new thermometer is free from air, allowing the mercury to move freely in the tube; and the index is pointed at both ends to allow the mercury to pass, instead of being ground flat to prevent it, as in Rutherford's. Unlike the ordinary minimum thermometer in use, it is suspended vertically, with its index resting on the surface of the column of mercury; as the mercury in the bulb contracts from decreasing temperature, that in the tube descends, and the needle follows. On the contrary, as the mercury expands and rises in the tube, having only a point to press against, it passes the index without moving it from its position, thus leaving the upper point of the needle indicating the minimum temperature. This instrument is shown in the engraving on p. 20 (fig. 8): it is to be read daily as the maximum thermometer; but, the minimum temperature occurring for the most part at about the time of sunrise, the reading of this thermometer in the morning is usually the lowest in the day.

11. The following table shows the most probable lowest temperature of the air in each month, in the suburbs of London:—

Month.	Lowest Temperature.	Month.	Lowest Temperature.
	°		°
January -	21	July - -	44
February -	18	August -	44
March -	24	September -	36
April - -	32	October -	32
May - -	37	November -	26
June - -	43	December -	24

In extreme cases the temperature in January may descend below 0°; in February to 5°; in March to 13°; in April to 27°; in May to 32°; in June, July, and August to 40°; in September to 32°; in October to 28°; in November to 22°; and in December to 18°.

12. The means of the lowest daily temperature of the air in every month are shown in Table 3 in the Appendix, p. 444; and in fig. 7, p. 19, the average lowest temperature of the air by night is shown.

13. *Range of temperature* during the day is simply the difference between the highest and lowest temperatures within 24 hours, as determined by the maximum and minimum thermometers respectively. The range is variable from day to day; within the year upon an average in the suburbs of London—

The range on	27	days is	less than	5°
,,	93	,,	is between	5 and 10
,,	108	,,	,,	10 ,, 15
,,	74	,,	,,	15 ,, 20
,,	35	,,	,,	20 ,, 25
,,	16	,,	,,	25 ,, 30
,,	2	,,	exceeds	30, one of

which may be as large as 40°.

The mean daily range is the mean of the daily ranges within the period; the monthly daily range may be found by taking the difference between the mean of all the highest daily readings of the thermometer and the mean of all the lowest daily readings; and in this way the preceding Table has been formed by taking the difference between the numbers in Tables 2 and 3.

Observed Mean Annual Temperature of the Air at the Royal Observatory, Greenwich, for every Year from 1771 to 1855, and Equated Elliptic Curve of the several Yearly Temperatures for the same Period.

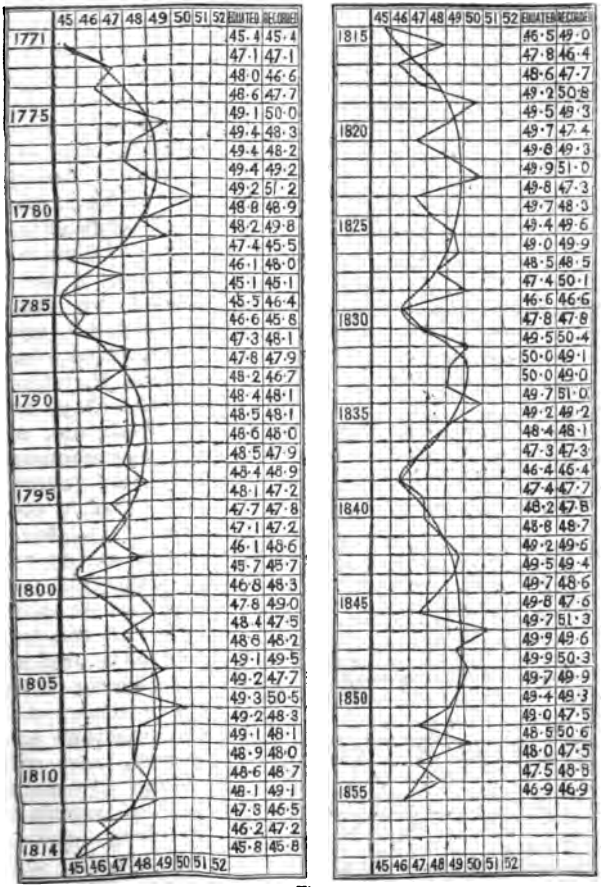


Fig. 9.

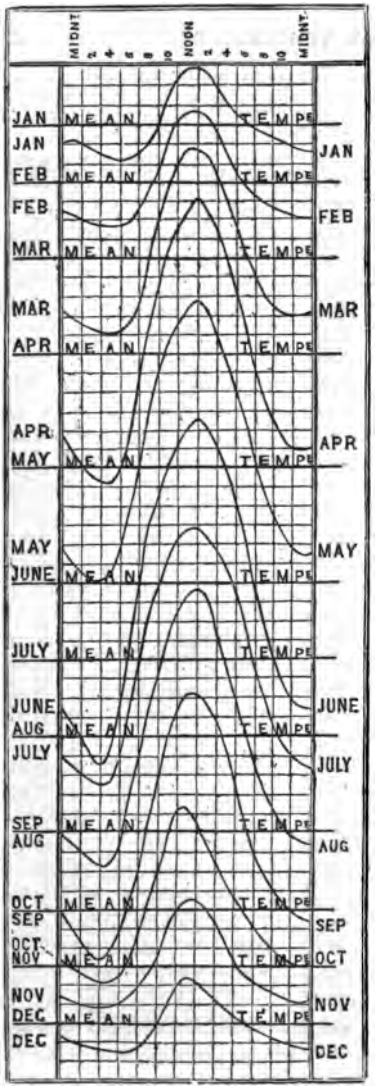


Fig. 10.—Diurnal Curves of Temperature of Air in every Month. [*Scale* 10° *to* 1 *inch.*]

14. *Temperature of the air* is understood to be that indicated by a correct thermometer properly placed, being effectually protected from the effects of radiation, reflection of heat, and all foreign influence. If an instrument thus placed be read at short and equidistant intervals throughout the day, as, for instance, at the commencement of every one of the twenty-four hours, or every two hours, we find that at each hour the temperature is different, (see fig. 10); by adding all the readings together, and dividing the sum by the number of observations, we obtain the *mean tempera-*

ture of the day. In like manner, by taking the sums of the mean daily temperatures for a week or a month, we obtain the *mean temperatures of the week or month*; by taking the mean of the 12 months in a similar way, we obtain the *mean temperature of the year*; and from a number of years we obtain the *mean* temperature of each month and the mean yearly temperature at a given place, as shown in Table 5 in the Appendix (p. 446). In this manner the mean yearly temperature at Greenwich has been found for a period of 85 years. These results are shown in fig. 9, p. 23, under the column headed "Recorded." By laying these numbers down on a diagram, and joining the several points by straight lines, the successive temperatures of each year are shown to the eye; from them, giving equal weight to every point, and starting from one lowest point to the next, the elliptic curve is formed, as shown in the diagram; then, by reading the values from the curve, the numbers under the head "Equated" have been found. The summation of the equated temperatures equals the summation of the recorded temperatures within each period. An inspection of the curves shows that periods of warm years come together, and periods of cold years come together; and it would seem, that the year 1856 was about the lowest part of one of the cycles; and, therefore, that a series of warmer years than those recently passed through may be expected.

15. By comparing the numbers in Table 5 (p. 446) with those in Tables 2 and 3 (pp. 443–44), it will be found that they are almost intermediate between them. In fact the mean temperature of any period differs but little from the simple arithmetical mean of the extremes, and the half of the sum of the maximum and minimum temperatures of each day gives an apparent mean temperature of the day. To this value, however, a correction is necessary to be applied, as determined by experiments extending over several years, and which are as follows:—*

* See my Tables in Phil. Trans., Part I., 1848, and Diurnal Range Tables, published by R. and H. Taylor, Red Lion Court, Fleet Street.

	°		°
January - -	0·2	April - - -	1·5
February - -	0·4	May - - -	1·7
March - - -	1·0	June - - -	1·8
July - - -	1·9	October - -	1·0
August - -	1·7	November - -	0·4
September - -	1·3	December - -	0·0

and these numbers are always to be applied subtractively to the simple arithmetical mean of the maximum and minimum thermometers.

16. *Range of temperature* is simply the difference between the highest and lowest temperatures in the period, as determined by the maximum and minimum thermometers respectively. The monthly mean daily range of temperature is the mean of the range of temperature each day in the month, or it is found by taking the difference between the monthly mean of the highest temperature by day and the lowest temperature by night. In fig. 7, the mean daily range of temperature is shown in each month, by the space between the two curves there laid down.

17. The best plan is to take observations of the dry-bulb thermometer, at those hours which are the least liable to interruption by the avocations of the observer, and to apply to their mean results the necessary corrections. Of the hours which are equally convenient, those are preferable about which the least changes are taking place, as then a small error in the time of observation will entail little or no error on the readings. Twice during the day the temperature of the air is at its mean value, and these times are as follows in the several months:—

	H.		H.
In January	at 10·0 a.m. and again at		8·0 p.m.
„ February	at 9·30 a.m.	„	6·40 p.m.
„ March	at 9·10 a.m.	„	7·20 p.m.
„ April	at 8·40 a.m.	„	7·0 p.m.
„ May	at 8·25 a.m.	„	7·30 p.m.
„ June	at 8·0 a.m.	„	8·0 p.m.
„ July	at 8·0 a.m.	„	8·5 p.m.
„ August	at 8·20 a.m.	„	7·20 p.m.
„ September	at 8·55 a.m.	„	7·20 p.m.

		H.		H.
In October	at	9·0 a.m.	„	7·0 p.m.
„ November	at	9·25 a.m.	„	6·45 p.m.
„ December	at	10·0 a.m.	„	7·20 p.m.

18. To determine the mean temperature of the air, it would therefore seem that it would be sufficient to take an observation at one of these two periods; but it must be borne in mind that at these times the changes of temperature are rapid, and consequently if the observations be made a little too soon, or a little too late, very considerable errors may be committed; therefore observations at these times, unless they are made very accurately with respect to time, are not worthy of implicit confidence.

19. If we compare the mean temperatures of places that differ considerably from each other in latitude, we shall find that the mean values are lower as we proceed north. If we compare the mean temperatures of places having the same latitude, we shall find that the mean value of those situated at the higher level will be less than those at the lower level; if we compare places having the same latitude, we shall find that the mean temperatures of those places situated inland will be higher in the summer months, and lower in the winter months than those situated in the vicinity of the sea. If we compare places differing only in their geological formations, we shall find that those places situated upon an arid, dry soil, will have a greater range of temperature than those situated upon a clayey, wet soil.

20. At all places the form of the diurnal variation is a simple progression, having one ascending branch and one descending branch (see fig. 10, p. 24), the maximum occurring early in the afternoon, and the minimum at about the time of sunrise; but the amount of the difference of the extremes at different places is very different, depending upon latitude, elevation, local exposure, the configuration and extent of the country; the nature of its soil, as more or less favourable to radiation and evaporation; proximity to the sea; direction of chains of mountains, &c.

LESSON III.

HYGROMETRY.

"And some seed fell upon a rock; and as soon as it was sprung up, it withered away because it lacked moisture."

1. After pressure and temperature, the next condition of the atmosphere to be investigated is its humidity. Water exposed to the air evaporates and mixes with it, in the invisible form of vapour. How much water will the air contain, and how is it supplied?

2. At different temperatures air is saturated with different amounts of vapour, for instance, at 0° Fahrenheit it is saturated by 55 grains in 100 cubic feet; but is capable of containing twice this amount by raising its temperature to 16°; its capacity is doubled again by a further elevation of 17°, and again by an increase of 19°. At the temperature of 27°, when air is saturated with moisture, it is capable of containing $\frac{1}{100}$ of its weight of water in the invisible shape of vapour; at 45°, when saturated, it contains $\frac{1}{100}$ of its weight; at 64°, $\frac{1}{50}$; and at 85°, $\frac{1}{25}$.

3. The great source of supply of moisture is the ocean, and all exposed water; but evaporation also proceeds from the surface of land, differing in amount according to peculiarities of surface, and over every variety of country, according to its soil, temperature, and humidity.

4. The most simple contrivance for measuring the amount of evaporation from a surface of water is that of an evaporating-dish of the same form and area as the rain-gauge, its receiving surface having been turned in a lathe. It should be rather more than an inch in depth, and furnished with a measuring-vessel, so that the amount of water evaporated within a given time, as 12 or 24 hours, may be estimated. In use, the evaporating-dish should be filled till the water is an inch in depth; and the amount less than an inch when measured will indicate the amount carried of by vapour. As the

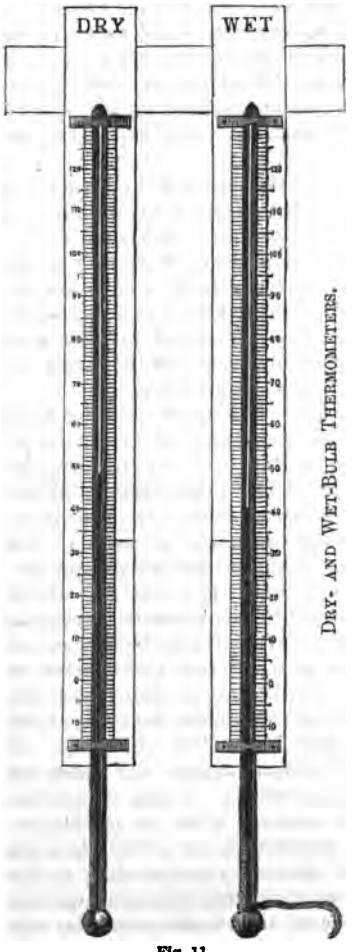
water of the great body of the ocean, of rivers, and deep water generally does not vary much in temperature although exposed to the sun, while water in an evaporating-dish exposed to the sun will often rise to a temperature much beyond that of the air, evaporation from the observing-pan will proceed too rapidly, if it be not situated in a shaded place, but fully exposed to the breeze.

5. When the amount of evaporation from damp earth is to be determined, it must be done by weighing a certain mass of earth before and after exposure.

The water in the invisible shape of vapour in the atmosphere, like air, is an elastic body, and its weight at the earth's surface is its elastic force; it is necessary therefore that this should be determined in order that we may ascertain how much the reading of the barometer is affected by the water mixed with the air.

6. *Tension or elastic force of Vapour.*—Water boils at 212° Fahrenheit under a pressure of 30 inches of mercury: it boils at a higher or lower temperature as the pressure is greater or less respectively. When the action of boiling begins, it shows that the elastic force of the vapour is equal to the pressure of the atmosphere; but though ebullition and very rapid formation of vapour take place, only when the elastic force of the vapour is equal to this pressure, vapour as before stated, will rise from the surface of water or ice at all temperatures, and with different elastic force at different temperatures. Dr. Dalton, of Manchester, was the first who ascertained by experiment the force at different temperatures below the boiling point, but the most recent and best determinations are those by Regnault ("Annales de Chimie"). These values, for every degree from 0 to 100, are given in my Hygrometrical Tables. The numbers in the Table show the length of a column of mercury corresponding to the tension of aqueous vapour at different temperatures, and to find the elastic force of the vapour present at any time in air, it is simply necessary to determine the tem-

perature of the dew-point; to seek for that temperature in the Tables, and the corresponding quantity will be seen by inspection.



Dry- and Wet-Bulb Thermometers.

Fig. 11.

7. Dry- and wet-bulb Thermometers.— The dry- and wet-bulb (fig. 11) thermometers consist of two thermometers, as nearly as possible alike. The bulb of the wet thermometer is covered with thin muslin, and around its neck is twisted a conducting-thread of lamp-wick — common darning-cotton, or floss silk; this passes into an adjacent vessel of water, placed at such a distance as to require about three inches of conducting-thread. The water-vessel should be placed on one side and a little beneath, so that the water within may not affect the reading of the dry bulb by its too near

vicinity. The water-vessel should always be supplied with rain or distilled water.

8. In frosty weather the water in the reservoir will be frozen, but this is no reason for the suspension of the observations; if the water upon the muslin is frozen at the same time, the readings are perfectly available. If the muslin be dry, it is necessary that it be wetted a sufficient time before the observation for the water to become frozen. When the weather is frosty, the muslin should be immersed in water after every observation.

Before use, the cotton lamp-wick should be washed in a solution of carbonate of soda, and pressed whilst under water throughout its length. In use it should be of such extent that the water conveyed be sufficient in quantity to keep the muslin moist, without having a drop attached to it. The amount of water supplied can be increased or diminished by increasing or diminishing the extent of the conducting-thread.

The mean monthly readings of the dry-bulb thermometer, corrected for diurnal range, are inserted in Table 5 in the Appendix (p. 446).

9. The mean monthly readings of the wet-bulb thermometer, similarly corrected, are contained in Table 6 in the Appendix (p. 447).

10. From the readings of the dry and wet-bulb thermometers, the dew-point is calculated by multiplying the difference between the readings of the dry thermometer and that of the wet by my factors in the following Table, and subtracting the product from the reading of the dry thermometer.

11. Temperature of the dew-point in summer is lowest a little before sunrise; as the sun ascends, evaporation increases, and the air receives a greater quantity of vapour, consequently the temperature of the dew-point increases till about noon, when it attains its maximum, and remains at this value till after the temperature of the air begins to decline, and then gradually decreases till the following morning.

Table, showing Glaisher's factors, by which the differences of readings of the dry-bulb and wet-bulb thermometers are to be multiplied, in order to deduce the difference between the temperatures of the air and dew-point.

Reading of Dry-bulb Thermometer.	Factor.	Reading of Dry-bulb Thermometer.	Factor.
°	°	°	°
25	6·5	37 and 38	2·4
26	6·1	39 to 41	2·3
27	5·6	42 to 45	2·2
28	5·1	46 to 50	2·1
29	4·6	51 to 55	2·0
30	4·2	56 to 63	1·9
31	3·7	64 to 72	1·8
32	3·3	73 to 86	1·7
33	3·0	87 to 100	1·6
34	2·8		
35	2·6		
36	2·5		

YEARLY CURVES OF MEAN TEMPERATURE OF THE AIR AND DEW-POINT.

[*Scale* 20° *to* 1 *inch.*]

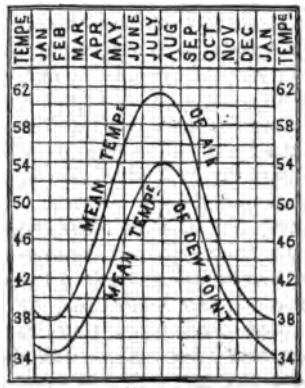


Fig. 12.

In winter its minimum occurs some hours before sunrise, and its maximum occurs at about the time of the maximum temperature of the air, and then gradually declines to the following morning.

12. The use of this Table is very simple. Example.—In Table 5, June 1841 the mean temperature of the air was 56·4, and in Table 6, that of evaporation for the same month was 52·6. Required the temperature of the dew-point?

Reading of dry bulb	56°·4
Reading of wet bulb	52·6
Difference	3·8
Factor for 56°	1·9
Product	7·2
Reading of dry bulb	56·4
Difference or temperature of dew-point	49·2

In Table 7, the dew-point observed was 49°·1.

13. Whenever the air of the atmosphere is saturated with moisture, the temperature of the air, evaporation, and dew-point is the same.

Whenever the temperature of the air is above the temperature at which it is saturated by the moisture which it contains, a portion of all exposed water undergoes a gradual diminution of bulk, and ice imperceptibly wastes away by rising in the atmosphere.

Whenever air is cooled below the temperature at which it is saturated, a portion of moisture is separated, in proportion to its newly-acquired temperature.

14. The air of the atmosphere is, however, generally in that state, that a depression of some degrees is necessary for the deposition of a portion of the water which it contains, and it will therefore take up water. The further it is removed from saturation, the more rapidly evaporation proceeds, and as it proceeds, the heat absorbed in the conversion of the thin film of water around the wet bulb into vapour will cause the reading

of the wet to decrease below that of the dry thermometer, and this depression in hot weather in this country may amount to 20°; in India and Australia at times to 30°. In cold weather, the difference will in general be small, but evaporation will proceed when the temperature is below 32°: great care is required in the observation when the temperature of the air is somewhat below 32°. At times it will happen, when the temperature has descended below this point, that the water on the bulb *has not begun* to freeze, and the reading of the wet bulb will be the higher of the two: these readings must not be recorded; when water has begun to freeze, the lower readings are taken. When the temperature is below 32°, the reservoir of water is useless, and the bulb must be moistened, some time before the observation, by a sponge or brush. When the temperature of the air has risen above 32°, the bulb of the wet thermometer, with its conducting-thread, should be immersed in warm water, for the purpose of removing any ice that may still remain on the bulb.

15. Having determined the temperature of the dew-point, the elastic force of vapour is at once extracted from a properly-constructed Table. Table 8 in the Appendix has been thus formed.

16. *Position of the Thermometers.*—They should be placed in a position sheltered from the direct rays of the sun; at such a distance from walls as not to be influenced by reflected heat; protected from rain, and from the effects of radiation, with the bulbs freely exposed to unimpeded circulation of air from all sides.

17. *Stand for carrying the Thermometers.*—In fig. 13 is an accurate representation of such a stand: it consists of a frame of deal boards, through all parts of which the air passes freely, for the purpose of carrying away any heat which may be conducted through them. It can be constructed by any carpenter. The whole revolves; its inclined side is always turned

towards the sun. On its face, the dry and wet bulb, the maximum and the minimum thermometers are

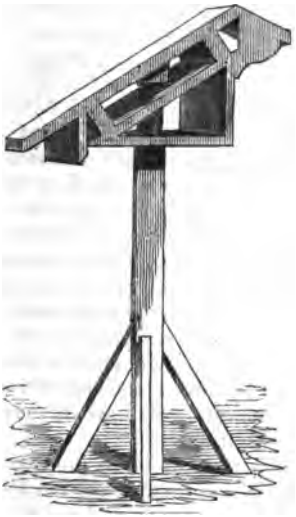


Fig. 13.

attached in such way that their bulbs project two or three inches below the frame, and about four feet above the ground.

LESSON IV.

VAPOURS.

"For what is your life? It is even a vapour, that appeareth for a little time, and then vanisheth away."

1. *Weight of Vapour in a Cubic Foot of Air.*—A cubic foot of vapour at 212° and under a pressure of 30 inches, weighs 258·4 grains; and air expands $\frac{1}{491 \cdot 13}$, or 0·0020361 for every increase of 1° of heat; it there-

fore expands 0·3665 of its bulk from 32° to 212°, and its expansion is uniform between these points. A cubic foot of vapour at any other temperature may be calculated from the following formula:—

$$\frac{1{\cdot}3665 \times 258{\cdot}4 \text{ gr.} \times \text{elastic force of vapour at temperature}}{30\left(1 + 0{\cdot}0020361 \times \overline{t - 32^{\circ}}\right)}$$

2. Table 9 in the Appendix contains the weight of a cubic foot of air, at the Royal Observatory, Greenwich.

3. *Degree of Humidity.*—With a knowledge of the amount of vapour which saturates the air at different temperatures, and the amount existing in the air at the time of observation, we are enabled to determine another important element, viz., the degree of humidity of the air. In calculating the numbers, saturation may be assumed as 100, or as unity, and air, without moisture, as zero. The degree of humidity is found by dividing the quantity of vapour at the temperature of the dew-point, by the quantity which would have been present had the air been saturated.

The numbers thus found at the Royal Observatory, Greenwich, are shown in Table 10 in the Appendix.

4. Air is most humid at night: as the sun ascends the temperature increases more rapidly than water evaporates to keep the same degree of humidity; the atmosphere, therefore, becomes less and less humid. This is particularly the case in summer, when the temperature of the dew-point is for some hours nearly stationary, whilst the temperature of the air is increasing.

When evaporation commences in the morning with the increase of temperature, vapour accumulates near the surface of the soil, till the air becomes heated and the daily ascending current of air sets in. It then ascends and spreads as long as the ascending current continues. Towards evening, when the temperature of the air is decreasing rapidly, the ascending current is checked, then ceases, and gives place to the descending current of night. Therefore there is a rapid increase

of evaporation and decrease of humidity during the day, and a rapid increase of humidity during the evening and night hours.

5. *Weight of a Cubic Foot of Air.*—A cubic foot of dry air at 32°, and under the pressure of 30 inches of mercury, weighs 566·86 grains. As the weight of air varies inversely as the volume, a cubic foot of air at any other temperature, under the same pressure, will be found by dividing 566·86 by the number expressing the volume of dry air after expansion from heat. Reckoning the volume of dry air at 32° as unity, for instance, required the weight of a cubic foot at 60°? We have seen that the expansion of volume is 0·0020361 for every degree of heat; this multiplied by $(60° - 32)$ $28 = 0·05701$, so that a cubic foot of air increases from 1 at 32° to 1·05701 for an increase of temperature from 32° to 60° and $\frac{566·86}{1·05701} = 536·3$ grains, the weight of a cubic foot of air at 60°.

Fig. 14. NEGRETTI AND ZAMBRA'S MAXIMUM THERMOMETER FOR SOLAR RADIATION WITH BLACKENED BULB.

6. A cubic foot of vapour at the same temperature and under the same pressure weighs 5·8 grains; the sum of these two weights is 542·1 grains, and a cubic foot of saturated air is 532·8 grains, and this would be the weight of a cubic foot of air under a pressure of 30 inches, and saturated with moisture: in all other cases it is to be calculated from the degree of humidity and pressure of the atmosphere.

7. Table 11 in the Appendix contains the mean weight of a cubic foot of air under its mean pressure, temperature, and humidity at the Royal Observatory, Greenwich.

8. *Solar Radiation.*—The sun's rays pass through

the atmosphere, exercising but little influence on its temperature till they reach the earth, accumulate there, and cause the earth to become much more heated than the air. Its amount is an important element in meteorology, and is determined by the excess of reading of a thermometer, placed near the surface of the earth, fully exposed to the direct rays of the sun, above that of the thermometer, placed to determine the temperature of the air in the shade. The solar-radiation thermometer (fig. 14), consists of a maximum thermometer, with blackened bulb, graduated on its own stem. In use it may rest on the forks of two Y's, precaution being taken to prevent lateral wind striking the bulb. In this situation its reading may be 150°, whilst that in the shade is 60°.

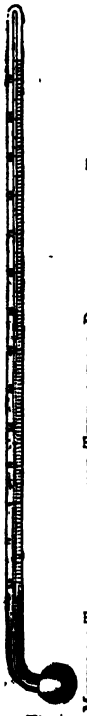


Fig. 15. Minimum Thermometer for Terrestrial Radiation with Transparent Bulb.

The average daily amount of solar radiation from November to February is 5° or 6°; in March 13°; in April 17°; from May to August 20°; September 18°; and October 10°.

In fine summer months the mean reading of the solar-radiation thermometer may exceed 100°, whilst in others it will not exceed 85°.

9. *Terrestrial Radiation.*—The amount of terrestrial radiation is of equal importance with that of solar radiation. From the surface of the earth heat is constantly escaping, and on cloudless nights the earth throws off heat by radiation more rapidly than the air, and its surface is reduced to a lower temperature than the surrounding air. Its amount is determined by the defect of the readings of a thermometer, with its bulb fully exposed to the sky, and placed on grass, or on a non-conductor of heat, as wool or flax, below those of the thermometer to

determine the temperature of the air in the shade. The terrestrial-radiation thermometer consists of a minimum thermometer with transparent bulb, and graduated on its own stem: in use it should rest on the fork of two Y's, so that the bulb is on the top of the grass, and not covered by a single blade.

A thermometer thus placed, when the sky is covered with low dense clouds, will read the same as that placed some feet above it; but on the clouds rising, or the sky becoming less cloudy, will read from 3° to 5° lower; and when the sky is cloudless and bright, and the air calm, the reading may be from 3° to 20° lower than the air. I once observed a difference of 28°·5 between the readings of two thermometers, the one placed on raw wool, and the other in air at the height of 8 feet. On calm and clear nights a terrestrial-radiation thermometer may read less than 32° in every month of the year.

10. The daily amount of terrestrial radiation is dependent on the amount of cloud. During any period when the nights are generally cloudy, there will be but little difference between the readings of the two thermometers: the mean difference monthly varies from 5° to 10°.

The greater coldness of grass than that of air in clear and calm weather, in places sheltered from the sun, but open to a considerable portion of the sky, may continue all day as well as night.

The formation of dew depends solely on the temperature of the bodies on which it is deposited, and never appears till their temperature decreases below that of the dew-point in their locality.

The amount of water deposited in the shape of dew is the largest on those substances which radiate heat freely, and on which the reading of a thermometer is lowest.

11. The great difference in temperature of the surface of the earth between day and night affords an explanation of the current of air denominated land and sea breezes.

During the day the air in contact with the heated earth becomes heated, expands in bulk, becomes specifically lighter, and rises in consequence, when the cooler air from the sea rushes in to supply its place, and thus causes the current called the sea breeze. During the night, on the contrary, the earth is cooled by radiation; the air in contact with it is cooled, becomes smaller in bulk, and specifically heavier than the air over the water, which parts with its heat much more slowly than the land, and a current from the land takes place.

12. *Condensation of Vapour.*—Whenever the temperature of the air is below that of the dew-point, a portion of vapour is deposited; and the forms of water so condensed are various, depending on circumstances. When this depression of temperature is small, as when saturated air is mixed with a stratum of a little lower temperature, the separation takes place in the air in very minute globules, which diffused over a large space, assume the form of clouds, mist, or, if near the earth, of fog. When the depression is large, the quantity of water separated from the air is great; and it falls in the form of rain, hail, or snow.

13. Clouds are visible collections of minute globules of water suspended in the atmosphere: they differ very greatly in respect of form and magnitude, depending on the quantity of vapour of which they are composed, the direction and force of the wind, &c. They have been classified by Luke Howard, F.R.S., into three primary formations, the cirrus, the cumulus, and the stratus, which are represented in the accompanying plate, fig. 16; and into four secondary, the cirro-cumulus, cirro-stratus, cumulo-stratus, and the nimbus.

Cirrus is composed of fibres or wisps or curling streaks, in appearance like a lock of hair, or a feather, sometimes resembling a brush. It occupies the greatest elevation, and is vulgarly known as "mares' tails."

Cumulus denotes a cloud in dense, convex heaps, with rounded, and frequently white, rocky surfaces, upon a

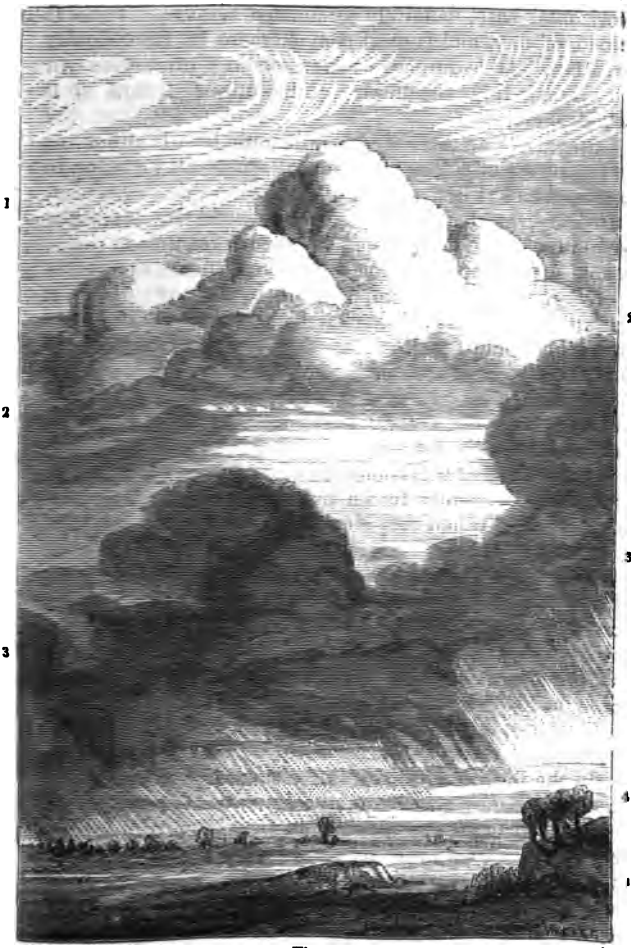


Fig. 16.

1, 1. CIRRUS.—2, 2. CUMULUS.—3, 3. NIMBUS.—4. STRATUS.

horizontal base, definitely terminated above. It is the cloud of day, and is most characteristic in fine summer weather. It is formed when ascending currents draw the vapour from the lower into the upper strata of the atmosphere.

Stratus is an extended, continuous, level sheet, and is the lowest of clouds: it forms at sunset and disappears at sunrise. It is the cloud of night.

Cirro-cumulus is intermediate between the cirrus and cumulus, and is composed of small, rounded masses, apple-shaped, and forming a net-like appearance.

Cirro-stratus is composed of bands of filaments, resulting from the subsidence of the fibres of the cirrus to a horizontal position, as they approach each other laterally. These clouds form horizontal strata, and exhibit the phenomena of the solar and lunar halos, as well as parhelia (mock suns) and paraselenæ (mock moons).

Cumulo-stratus is composed of cumulus clouds heaped together, frequently into a pyramidal shape, increasing in density. When this cloud assumes a bluish or black tint, near the horizon, it is ready to pass into nimbus.

Nimbus is the rain cloud: it is dense, and of a uniform black or gray tint, in a horizontal sheet with fringed edges.

14. *The amount of sky covered by clouds* is represented numerically in tenths, of which 0 indicates a cloudless sky, and 10 one entirely covered by cloud. In estimating the proportion when the sky is partially covered, it must be borne in mind that in the zenith only the forms and outlines of clouds are exhibited, and the space they cover and the intervals between them distinctly seen. In estimating, therefore, the amount of cloud, regard must be had to this circumstance, and the observer's judgment formed rather from the appearance of the sky within 60° of the zenith, than from the appearance of the clouds near the horizon. The average amount of sky covered by cloud in the suburbs of London is as follows:—

January	7·7	July	6·9
February	7·4	August	6·5
March	6·6	September	5·9
April	6·1	October	6·9
May	6·1	November	7·2
June	6·1	December	7·4

15. *Mists* differ from clouds only in occupying a lower elevation: their origin is the same, viz., vapours which rise from water and the surface of the earth.

16. *Fog* is vapour resting on the surface of the land or water, and at times is so dense that objects cannot be distinguished at the distance of a few yards. During calm weather the surface of rivers, lakes, &c., are frequently in the morning covered with fog, owing to the water during the night being at a higher temperature than the air; the stratum of air, therefore, in immediate contact with the water is heated, and rises, in consequence, till it meets with the cold air above—is cooled, and its moisture precipitated. Such fogs are soon dislodged by the heat of the sun, because the air increases in temperature, and becomes capable of supporting the vapour.

LESSON V.

RAIN, SNOW, &c.

"Fire, and hail; snow, and vapours; stormy wind fulfilling His word."

1. When the water separated from the air is large, and the temperature is above 32°: it falls in drops varying from the thirtieth to one-third of an inch in diameter.

2. When two currents of saturated air of different temperatures meet and mix together, the resulting temperature will be the mean of the two, but the resulting tension of vapour will always be higher than that belonging to the mean temperature; consequently there will be an excess of vapour which will be precipitated in the form of water. Let us suppose two currents of

air, the one having a temperature of 50°, and the other a temperature of 70°, and that these two currents are mixed together,—

The elastic force of vapour at 50° is	-	0·361
„ „ 70° is	-	0·733
Sum	- -	1·094
Mean	- -	0·547

3. The mean temperature of the two currents is 60°, and the mean of their elasticities is 0·547. The elastic force of vapour at 60° is 0·518 inches; therefore, after the intermixture of the two currents, a quantity of vapour corresponding to the elastic force of 0·029 inch will remain; and as this excess cannot be held in solution by air of the temperature 60°, it will be separated in the form of clouds, or of rain, according to circumstances, as before stated.

4. The drops of rain when they begin to fall are of the temperature of the stratum of air in which they are situated, and if this be of less temperature than that of the dew-point of the strata through which they pass, they increase as they descend; but if otherwise, and the air be dry, they decrease, and it may happen that none reach the ground.

5. To determine the fall of rain, that is, to determine the depth of water in inches that would be found on a perfectly level surface, if the fall remained there after a shower, a day, a month, or a year is important. The form of gauge should be simple, and such that the water collected should not be subjected to loss by evaporation. Its receiving surface should not be rectangular, a figure difficult to obtain correct in all its angles, and very liable to have its shape distorted by careless treatment. We can, however, always insure a perfect circle, by the use of the turning-lathe: the receiving surface, therefore, should be circular; and its area calculated, multiplied by 252·525 grains (the weight of one cubic inch of water), for the purpose of determining the weight of a cylinder of water, an inch in height,

and of a base equal to that of the receiving surface of the gauge.

6. The engraving, fig. 17, shows the form of gauge in general use by the members of the British Meteorological Society; the diameter of the receiving surface is about 8 inches, attached to an inverted funnel, terminating in a tube of small diameter, bent upwards; this funnel is connected with a cylinder or reservoir

GLAISHER'S RAIN GAUGE.

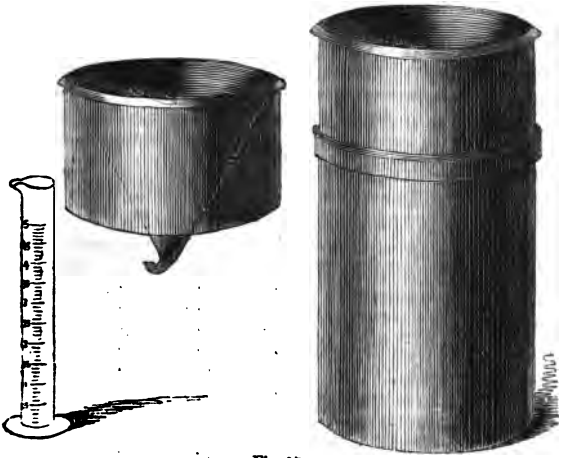


Fig. 17.

about 12 or 13 inches in height, by a water-joint. In use, the cylinder is sunk about two-thirds of its height below the surface of the soil, so that the receiving surface is about 5 inches above the ground.

7. If the gauge be read once a-month only, the quantity may be ascertained by simply measuring the depth of water in the reservoir; if it be read daily, or after a shower, it is necessary to have a measuring vessel of small diameter; a glass vessel graduated into inches in accordance with the calculated weight of water for the

area of the mouth of the gauge is requisite for this purpose.

8. The gauge should be placed in a locality free from trees, buildings, or walls—in fact, in as open a space as possible.

If a second gauge be placed at a higher level, as on the roof of a building, it should be read frequently, to prevent the loss by evaporation; and if so placed, the quantity of rain will generally be very much less than at the lower level, as shown in the following table.

TABLE showing the Amount of Rain collected in each Month of the Year 1855, at the Royal Observatory, Greenwich, in Gauges placed at different distances from the soil.

1855. Month.	Monthly amount of Rain collected in each Gauge.		
	Osler's Anemometer Gauge.	On the Roof of the Library.	Cylinder partly sunk in the Ground.
	In.	In.	In.
January .	0·2	1·0	1·5
February .	0·2	1·4	1·0
March . .	0·5	1·3	2·0
April . .	0·1	0·1	0·1
May. . .	0·5	1·5	1·8
June . .	0·5	0·7	0·9
July. . .	3·1	4·8	5·3
August . .	0·6	0·8	1·4
September .	0·8	1·1	2·0
October . .	2·6	4·5	5·2
November .	0·5	1·1	1·5
December .	0·4	0·9	1·1
Sums	10·0	19·2	23·8

The heights of the receiving surfaces of the gauge are as follows:—

	Above the level of the sea. Ft.	Above the ground. Ft.	In.
Osler's Anemometer Gauge - -	205 - -	50	8
Gauge on the Roof of the Library -	177 - -	22	4
Cylinder Gauge - - - - -	155 - - -	5	

One observation daily is generally enough; but at times it is desirable to observe at short intervals, as when, in engineering operations, it is of importance to know the greatest fall in the shortest interval of time.

9. The fall of rain is different in different places; and is larger on mountains than on plains; greater in the neighbourhood of the sea than at sea; greater on the west than on the east coast of our country.

Thus, in the valleys, in the lake districts of Cumberland and Westmoreland, the usual fall of rain varies from 50 to 100 inches in depth in a year; and these large quantities increase with the elevation till the greatest annual depth of rain is obtained at an elevation of about 2000 feet: at higher elevations, it then decreases in amount. Dr. Miller, F.R.S., of Whitehaven, to whom we are indebted for this information, has recorded the very large fall of 38·9 inches in a single month, a quantity exceeding the average annual fall of the whole country. The quantity that falls annually in Jersey and Guernsey, is about 31 inches; in Cornwall and Devonshire, from 30 to 40 inches—exceeding the latter in some places: it is about 30 inches in the Isle of Wight, and over the South of England; 25 inches about London; 24 inches about Bedford, York, and Durham; 27 inches near the east coast; 30 inches near the west coast; about 27 or 28 inches elsewhere. In winter the rain-drops may become frozen and fall in this shape.

10. Table 12 in the Appendix shows the fall of rain monthly at the Royal Observatory, Greenwich.

11. *Electrometer.*—The simplest form of electrometer consists of two thin slips of gold-leaf suspended from an insulated conductor: this instrument acts upon the principle that bodies similarly electrified repel each other. The electricity is collected by a flame—a cigar-lighter, for instance, held by a clip at the end of a brass rod. The kind of electricity with which it is charged is determined by the use of excited glass or a stick of sealing-wax: by the application of the former, if the electricity be positive, the leaves will still further

separate; and if negative, will approach each other. By the application of excited sealing-wax, the reverse takes place, and they will approach each other if charged with positive, and will open still more if with negative electricity. Other forms of electrometers act upon the same principle, and are prepared for electricity of various intensities.

At the end of each month the means of the several subjects of numerical research should be taken. At the end of each year these should be arranged in one table, and the mean values of every element for the year determined: an example of such a table for the year 1855, at the Royal Observatory, Greenwich, is shown in Table 13 in the Appendix.

12. MINOR PHENOMENA DEPENDENT UPON REFLECTION OF LIGHT.—The *Rainbow* is a frequent phenomenon, appearing in the region of the sky opposite to the sun, when rain is falling at the same time that the sun is shining. Under these circumstances, if the observer turns his back to the sun, he sees a brilliant-coloured arch projected on the opposite cloud, exhibiting all the colours of the solar spectrum. When perfect, there are two bows, the inner being called the primary, and the outer the secondary rainbow; their common centre is in the prolongation of the line joining the centre of the sun, and the eye of the observer.

13. *Electrical state of the Atmosphere.*—The atmosphere affords almost daily indications of electricity: in fine weather, and generally at times when no rain, hail, or snow is falling, the electricity of the atmosphere will be positive, and is negative generally when rain, hail, or snow is falling. During storms accompanied by thunder, lightning, and rain, the electricity varies in amount and kind, not unfrequently changing several times in quick succession, and at such times usually settles into negative electricity. During the passage of a cloud across the zenith, it often happens that the electricity changes to negative, on the edge of the cloud reaching the zenith—remains negative whilst the cloud

is passing, and again becomes positive on the cloud leaving the zenith.

14. Lightning and thunder exhibit the phenomena of electricity on a large scale; the former is caused by the passage of electricity between one cloud and another, or between a cloud and the earth, and the latter is the noise produced by such passage.

15. The Aurora-borealis is supposed to be in some way connected with the electrical state of the atmosphere; certain it is that there is an intimate connexion existing between the magnetism of the earth and the Aurora-borealis. In every case that I have heard of, the Aurora being present at that time, the magnets have been in a state of disturbance. Its precise nature is, however, still obscure.

16. *Ozone.*—Among meteorological phenomena, attention has recently been drawn to certain effects produced on chemical test-papers when exposed to atmospheric influence, which it is inferred are produced by the presence in the air of a chemical element or compound, Ozone (ὀζω, I smell), varying in the intensity of its reaction or amount under different circumstances. The term was applied, in 1848, by Dr. Schönbein, of Bâle, to the peculiar odour perceptible during the action of a powerful electric machine, and in the decomposition of water by the galvanic battery. It was afterwards ascertained that a similar smell is developed by the influence of phosphorus on moist air, and in many instances by slow combustion. For some time the existence of ozone, as its name indicated, was recognised by the odour alone, that being its sole known character; but another fact was soon established, that some element of the atmosphere endowed with this peculiar smell possessed likewise an oxidising power. The evidence, then, of the existence of ozone depends entirely on these two characters. In experimenting in close vessels on a limited scale, it is possible to demonstrate both of these properties. When, however, we direct our attention to the atmosphere, it will be impossible to detect

ozone by more than one character, viz. its oxidising property.

The directions for noting the presence and measuring the amount of ozone in the atmosphere are very simple, being the free exposure to the atmosphere (protected from rain and the direct rays of the sun) of a small strip of dry paper, previously saturated with a solution of starch and iodide of potassium. There are two preparations of test-papers, the one by Dr. Schönbein and the other by Dr. Moffat of Hawarden: by the former the amount of discoloration is determined by a momentary immersion of the test-paper in water, and comparison with a scale of purple tints numbered from 1 to 10; and by the latter by comparison at once with a scale of brown tints numbered also from 1 to 10. The same purple tints will be shown by Moffat's paper on immersion in water, but by the use of the purple tints the paper is valueless afterwards; but when the intensity is determined by the brown tints, if kept in the dark, or between the leaves of a book, the colour may be retained for several years.

The amount of ozone at stations of low elevation is small: at stations of high elevation it is almost always present; and at other and intermediate stations it is generally so. The presence and amount of ozone would seem to be graduated by the elevation, and to increase from the lowest to the highest ground.

The amount of ozone is less in towns than in the open country, at the same elevation; and less at inland than at sea-side stations. During the presence of the epidemic of cholera, in London, in the year 1854, scarcely any ozone was recorded at any station near the river Thames, but at stations of high elevation it was of general occurrence. This may be accounted for by the presence of large quantities of organic matter, decomposed by ozone, itself being simultaneously destroyed.

17. The next class of phenomena is that produced by the passage of light through crystals of ice floating in the atmosphere. The angular form of snow crystals

is such as to determine the rays of light in directions giving rise to halos (coloured circles or rings surrounding the sun or moon), and, where they cross each other, of parhelia (mock suns), and paraselenæ (mock moons). In looking for these phenomena, particularly those connected with the sun, it is imperatively necessary to know where to look for them, and this will be known by the following particulars:—

18.—SOLAR HALOS are circles round the sun, of different diameters, some coloured and some not.

1st. A coloured circle may appear at the distance of 7° to 10° from the sun.

2nd. A coloured circle may appear at the distance of 22° 30′ from the sun.

3rd. A coloured circle may appear at the distance of 46° from the sun.

And these may all appear at the same time. The *red* colour is at the *innermost* part of the ring.

4th. A colourless circle may appear at the distance of 90° from the sun. [This is of rare occurrence. I have never seen one.]

5th. A horizontal white circle passing through the sun may appear.

6th. Inverted arcs of circles, touching the halos of 22½°, and 46° at their highest and lowest points may appear.

19. MOCK SUNS (*Parhelia*) are images of the true sun appearing simultaneously with him.

7th. The parhelia, or mock suns, are coloured, the red part being nearest the sun. They appear as follows:—

8th. With halos—They usually occur a little beyond the points where the halos intersect the horizontal circle passing through the sun (5); if, therefore, the horizontal circle be visible, the place is immediately determined; but if not, by considering where such a circle would cut the visible halos, the place is indicated.

9th. Parhelia sometimes appear in the halos vertically above the true sun, and also in the inverted arcs, vertically above the true sun.

10th. A mock sun sometimes occurs in the part of the sky exactly opposite to the true sun, and in this case it is called anthelion.

11th. Mock suns frequently occur at the distance of 22½° from the sun, in a horizontal plane passing through the sun, at the time when no halos are visible.

12th. Vertical lines passing through the sun, and circles containing the sun in their circumference, are to be looked for. Their several phenomena may continue visible for several hours.

20. LUNAR HALOS and *Paraselenæ*, or images of the moon,

13th. Are much more easily seen than solar halos. The same remarks apply to them as to solar halos, and also to mock moons.

21. GLORIES, CORONÆ, &c.—The coloured rings seen round the sun and moon, when thin, white clouds, generally of a cirro-cumuli kind, pass over their discs, are carefully to be distinguihed from the true halos.

14th. They are much smaller, being immediately round the sun or moon, and their whole diameters vary from 1½° to 12°. When large, their colours are beautiful, and several series of colours appear at once.

15th. The diameter of any ring is not constant for any length of time.

16th. The *red* occupies the *outermost* ring, instead of the innermost, as in the true halo.

22. Of minor phenomena not dependent upon instrumental aid for observation, are those relating to the congelation of water. It is well known that water freezes at a temperature of 32°, but the first process of its change from a fluid to a solid state is not so well known. As seen on the surface of ponds, or wayside water during periods of frost in winter, the method of

its change may be described as follows:—The first commencement of congelation is attended with the almost simultaneous appearance of long needles, radiating for the most part from the sides of the bank, within the margin of the water: these increase in length, sometimes appearing divergent and sometimes parallel. Those at the sides are generally the first to make their appearance, but, by degrees, others similar in form, and the thinnest possible, gradually form at intervals on the surface, transversely, and in all directions, until the very smallest interstices are filled. The needles are laminated, as may be distinctly seen on the surface of thin and newly-formed ice. But the freezing of water is not always so accomplished: it frequently happens that the needles on the surface, generally those towards the centre of the pond, group themselves into stars of three or six radii, feathered on either side with fine spiculæ, which quickly form a crystalline encrustation of serrated outline, giving to each radial arm or pinna the appearance of a frond of fern. Fig. 18 is a representation of this the most elementary form of water crystal, as commonly seen on water just below the freezing point, and may be seen extending to a length of upwards of 18 inches radius, and again small and beautifully defined, not exceeding an inch in diameter. The interstices between these crystals are frequently filled in here and there with a single pinna of the same, and everywhere besides with needles crossing and recrossing in all directions. If the frost continue, in the course of a few hours as the ice thickens these beautiful markings become obliterated. They are best witnessed on the cold morning of a fine clear winter day, when the process of congelation is proceeding slowly: at such times the water by the road side, or the surface of a pond, affords matter of the highest interest and infinite study.

Fig 18.

23. These processes in part may be repeated within doors and during severe weather, by exposing in shallow vessels of wood, porcelain, &c., about an inch depth of water, under an open window, in a room of about 32° temperature. By this means the process may be seen in miniature, but the observer should be prepared to watch repeatedly before he can hope to see it displayed in full perfection. The annexed engraving (fig. 19) is copied from the surface of a bath of water so exposed: the entire surface was covered with groups equally interesting and graceful.

24. The forms of hoar frost, as deposited on various out-door substances, are infinitely varied: hoar frost or white frost is simply frozen dew, and may be seen to great perfection before sunrise on mornings following cold and cloudless nights, during which the radiation of heat from the earth is large, the cooling effect of which on the passing air is to cause an abundant deposition of dew, which on becoming frozen gives rise to innumerable combinations of spiculæ, varying in arrangements and grouping according to the nature of the substances on which the dew is deposited. It varies very greatly on the leaves of different plants, which of itself may be said to constitute a study. During the years 1841 to 1845, whilst carrying on a course of experiments on the radiation of heat, I paid considerable attention to the subject: the results of these experiments are published in the Philosophical Transactions for the year 1847.

Fig. 19.

25. Every one is familiar with the beautiful en-

crustations on the surface of window-panes in frosty weather, another of this class of phenomena, and produced by the same process of congelation; and which the observer may perceive for himself by effacing with his hand a portion of that already crystallized, and breathing upon it anew. After a short interval there will simultaneously appear along the inner margin of the part an almost imperceptible fringe of spikes or needles, which speedily lengthen—a few generally exceeding the remainder very greatly in length. They are most frequently curved, and soon assume the arborescent form: sometimes the lines of crystallization will run parallel to each other, in undulations, so as to give rise to beautiful semblances of the most varied objects.

The graceful and flowing curves occasionally exhibited about the freezing point on various substances may be illustrated in the following engraving (fig. 20), the

Fig. 20.

original of which was observed upon a wooden hand-rail in the open air, and was continued on for a length of seven feet.

26. The crystallization of water or vapour in the upper regions of the air is a still more interesting field of inquiry, and leads us to the consideration of snow. Very little is as yet known respecting the formation of snow, excepting that it is water congealed in the higher regions, and can therefore only be formed at or below a

temperature of 32°. It falls for the most part in flakes of such density, that from 10 to 12 inches in depth of fresh-fallen snow produces water to the depth of an inch; but it is not always that snow assumes the form of flakes, it occasionally falls in clusters of small needles or spiculæ, sometimes broken in their descent into the finest possible fragments, while at other times it descends in minute and highly-crystallized stellar particles, designated by ancient writers as Polar snow, and generally supposed to be confined to the more northern latitudes: its density in this form is somewhat greater than in flakes, 8 inches of snow producing about an inch of water. The simple or elementary crystals of snow, formed at or near the freezing-point, bear considerable analogy to those on the surface of water already referred to, but, unlike them, are in these latitudes invariably minute and rarely exceed 0·5 inch in diameter. Water crystallizes at an angle of 60 degrees: in accordance with which law its figures are compounded of hexagons, and their component parts respectively arranged at an angle of 60°. The combinations so given rise to may be considered, according to our present information on the subject, illimitable, but always, however complex, referable to one of two bases, viz., a plane hexagon, or a simple elementary star. Fig. 21, drawn as seen through a high-power Coddington lens, and compounded of solid hexagons, is selected as illustrative of the former class; and fig. 22, made up entirely of spiculæ, as illustrative of the latter. The great variety observable in the conformation of these bodies is remarkable, and adds not a little to the complexity

Fig. 21.

Fig. 22.

of the problem, respecting the conditions and circumstances attending their crystallization. They descend simultaneously in differently-progressive stages of development, and distinct classes, or rather distinct orders of crystals. Fig. 23 is illustrative of a crystal in an intermediate stage of formation. Fig. 24 is of a very high order, and fell on a day when the temperature differed very greatly from the average for the time

Fig. 23.

Fig. 24.

of year. Unlike those of which I have been speaking, it was an almost imperceptible speck, and it was difficult to conceive how it could contain such an aggregation of solid figures. Some crystals are double, that

Fig. 25.

Fig. 26.

is, two similar crystals are united by an axis at right angles to the plane of each. Such is fig. 25, which is one of the most simple types I have been able to select. The manner of the subsidence of these bodies on first melt-

ing, is a very important point of observation; if it proceed gradually, every line becomes relaxed, and bent inwards, and every angle blunted. Thus a figure laden with prisms upon the main arm will assume the appearance of fig. 26, which was drawn while melting, and to the eye of a casual observer, presents a very anomalous appearance. In the Report of the British Meteorological Society for 1855, I have treated at length on these interesting bodies,* and have appended illustrations of more than 150 varieties; but the plan of the present work will not here permit me to enlarge on the subject further than to call attention to the manner of the crystallization of water, which as occurring on the surface of the earth, as falling in the familiar form of snow, or as deposited in the form of hoar frost—call into operation the same code of laws. In the case of snow, its crystallization is, I am convinced, intimately connected with the electrical and chemical condition of the air generally; and in this opinion I am confirmed both by Dr. Smallwood of Isle Jesus, Canada, and Sir Edward Belcher: the latter gentleman, in his work on the Arctic Seas, recently published, has devoted some pages to the subject, having, he observes, for many years regarded them with great interest, both in a mineralogical and chemical point of view, independently of their belonging to the ordinary range of meteorological inquiry. Sir Edward Belcher says, "three classes were made by me, and termed:—

1. "Stars and garters—from their resemblance to the order of knighthood and perfection of crystal, or such as might result from temporary currents of electricity suddenly forming and condensing vapour, as compared to fine, light, passing showers between bright gleams of sun. It will be understood that such light rain, which in other climes would not obscure the sun, would in the state of snow be more opaque.

* In the 'Art Journal' for the months of March and April 1857, is an article on the Application of Snow Crystals for the purpose of Design.

2. "Rain—heavy flocculent snow, cohering, and into which the travellers and sledge sank deeply, warning the intelligent officer that he had better pitch his tent, and reserve the strength of his crew for a period when search would be rational.

3. "Bad-omened—fine, spicular snow, the result of No. 1 broken by the wind into fine particles: this induced us to expect the sharp rain attended by wind of other climates, but did not hinder travel,—it was not so opaque as to impede vision.

"These remarks apply simply to the question of utility in such pursuits; and, as regards the terms selected by me, were adapted to the minds of those by whom I was surrounded, and who fully understood, in their own way, the full intent of the freemasonry which most leaders maintain with their followers."

JAMES GLAISHER.

A WINTER STORM.

NATURE! great parent! whose unceasing hand
Rolls round the seasons of the changeful year,
How mighty, how majestic, are thy works!
With what a pleasing dread they swell the soul!
That sees astonished! and astonished sings!
Ye too, ye winds! that now begin to blow,
With boisterous sweep, I raise my voice to you.
Where are your stores, ye powerful beings! say,
Where your aërial magazines reserved,
To swell the brooding terrors of the storm?
In what far distant region of the sky,
Hushed in deep silence, sleep ye when 'tis calm?
When from the pallid sky the sun descends,
With many a spot, that o'er his glaring orb
Uncertain wanders, stained; red fiery streaks
Begin to flush around. The reeling clouds
Stagger with dizzy poise, as doubting yet
Which master to obey: while rising slow,
Blank, in the leaden-coloured east, the moon
Wears a wan circle round her blunted horns.
Seen through the turbid fluctuating air,

The stars obtuse emit a shivered ray;
Or frequent seem to shoot athwart the gloom,
And long behind them trail the whitening blaze.
Snatch'd in short eddies, plays the withered leaf;
And on the flood the dancing feather floats.

* * * * * * * *

Ocean, unequal pressed, with broken tide
And blind commotion heaves; while from the shore,
Eat into caverns by the restless wave,
And forest-rustling mountains, comes a voice,
That solemn sounding bids the world prepare.
Then issues forth the storm with sudden burst,
And hurls the whole precipitated air,
Down, in a torrent. On the passive main
Descends th' ethereal force, and with strong gust
Turns from its bottom the discoloured deep.
Through the black night that sits immense around,
Lash'd into foam, the fierce conflicting brine
Seems o'er a thousand raging waves to burn:
Meantime the mountain-billows, to the clouds
In dreadful tumult swelled surge above surge,
Burst into chaos with tremendous roar,
And anchored navies from their stations drive,
Wild as the winds across the howling waste
Of mighty waters: now th' inflated wave
Straining they scale, and now impetuous shoot
Into the secret chambers of the deep,
The wintry Baltic thundering o'er their head.
Emerging thence again, before the breath
Of full-exerted heaven they wing their course,
And dart on distant coasts; if some sharp rock,
Or shoal insidious, break not their career,
And in loose fragments fling them floating round.

THOMSON'S SEASONS.

Biography.

LINNÆUS AND JUSSIEU.

BY HUGO REID.

1. In the early progress of a science, we may observe two distinct stages: the first, the simple accumulation of a few facts relating to it; the next, the comparison of these facts with each other, and thence the inferring some general rules or laws which are found to prevail amongst them. It is when the latter stage is arrived at, that the branch of knowledge assumes a systematic and a scientific form, and becomes truly entitled to rank as a science; and, usually, the names of a few very eminent men are associated with each division of human knowledge, as having contributed greatly in enabling it to enter this higher and more advanced stage of its progress. The seventeenth and eighteenth centuries will ever be memorable in the history of the progress of knowledge, for the number of sciences which then for the first time assumed a distinct and systematic form. In the seventeenth century, the genius of Kepler, Galileo, Napier, Hooke, Halley, Huyghens, Leibnitz, and Newton established on a scientific basis, astronomy, mathematics, optics, and mechanics. In the following century, the natural and experimental sciences—botany, zoology, mineralogy, geology, chemistry, heat, and electricity—first assumed a scientific form. The first four of these are often spoken of under the term "Natural History." Linnæus, at the beginning, and Jussieu at the end of the century, made themselves famous by their contributions to natural history, more especially to that part of it which relates to plants—botany.

2. Charles Linné or Linnæus, was born at Rashult, a

village of Smaland in Sweden, in the year 1707. His father was at first assistant minister, and afterwards pastor or rector, of the neighbouring parish of Stenbrohult. His means were moderate, but he had a garden and a few fields, which he cultivated with much care, and which no doubt contributed to turn the attention of the son to flowers and plants at a very early period. But the child had a strong natural love—almost a passion—for flowers, and, when not more than eight years of age, used to wander over the neighbouring country and collect the wild flowers, which he would transplant into a corner of the parsonage garden which was allotted to him. His father intended to rear him to his own profession—that of a clergyman; and sent him to school at Wexio, where he contrived to learn Latin; but evinced so much indifference or dislike to the study of the ancient languages, and so often neglected his lessons or classes to botanise in the country, that his teachers acquired a very poor opinion of him, viewed him as almost a dunce or fool, and made such a report of him to his father, that the latter had serious thoughts of taking their advice, giving up all intention of sending him to any of the learned professions, and of binding him apprentice to a tailor or shoemaker.

3. From this, however, he was rescued by the penetration and kindness of a physician named Rothman, who, having conversed with him, perceived that he was worthy of a very different fate. He lent him a copy of "Tournefort," then the best work on botany, and soon succeeded in getting him placed with Stobæus, professor of natural history in the University of Lund, who employed him in copying; and finding that he sat up at night studying, encouraged him, gave him the use of his library, and by his liberality was instrumental in getting him sent to the University of Upsal.

4. There Linnæus had great opportunities for pursuing his favourite studies; but his means were slender, and he was often exposed to great difficulties and privations.

He maintained himself mainly by teaching Latin to the other students; but, in spite of this aid, often was uncertain how to get his next meal, used to be under the necessity of stopping up holes in his shoes with paper or card, and, it has been said, was sometimes glad of a gift of a pair of old shoes from a companion. Such were some of the early struggles of a man who was afterwards to fill the world with his fame. Latterly, he was aided at Upsal by Celsius, the professor of theology, who required his assistance in the preparation of a work on the plants mentioned in the Holy Scriptures, and by Rudbeck, the professor of botany, who gave him some charge connected with the botanic garden, and occasionally employed him to lecture for him. In the year 1732 he was selected by the Royal Society of Sciences at Upsal to travel through Lapland, collect specimens, and make a report on the natural history of that region.

5. On his return he wished to lecture at Upsal, but was prevented by the opposition of one of the professors named Rosen, who was said to be jealous of the fame he had acquired, and took advantage of a regulation against lectures by those who had not a degree. He retired to Fahlun in Dalecarlia, where he endeavoured to make a living by the practice of medicine, and giving lessons in mineralogy: there he met his future wife—but she insisted that their marriage should be postponed for several years, and, it has been said, assisted him with means to procure a degree. He soon went to Hamburg, and then to Holland, where he met the illustrious Boerhaave, who was the means of introducing Linnæus to a wealthy and enlightened patron, George Clifford, a banker, who had a passion for natural history, and at Harbecamp, between Haarlem and Leyden, had a magnificent garden, with a fine cabinet of minerals, and an extensive library. Clifford appreciated the genius of Linnæus, gave him a home and access to his fine collections in natural history, and he resided with his hospitable patron for three years.

6. This was what Linnæus required—peace of mind and leisure to devote himself to study, and to the developing of the great ideas for reforming natural history, which had long been floating in his mind—freedom from the harassing anxieties of the deadly struggle for subsistence. These three years were nobly employed; the germs of all he did afterwards were then formed. In 1735, the first edition of his "System of Nature, or the Three Kingdoms of Nature, systematically arranged, in Classes, Orders, Genera, and Species," was published at Leyden; and at Amsterdam in 1736, his "Principles of Botany" (*Fundamenta Botanica*). These works were little more than mere outlines, afterwards filled up in subsequent editions of his *Systema Naturæ*, in his *Genera Plantarum*, published at Leyden in 1737, in his *Philosophia Botanica*, published at Stockholm in 1751, and in his *Species Plantarum*, Stockholm, 1753.

7. It is not easy for us, who find such vast stores of useful and interesting knowledge ready to our hands, and not only ready, but nicely arranged for us, so that we can come at any part we may wish quickly and with little trouble—it is not easy for us who enjoy these great advantages to imagine the time, labour, trouble, patient industry, and genius, that have been necessary to amass the knowledge now possessed by man, and to give it that scientific form which renders it so accessible to us, as learners, and so useful to those who are gifted with genius to extend it by further discoveries. But we should sometimes look back, and inquire—How has this great work been done? Who did it? To whom are we indebted for this vast amount of knowledge, at once so useful and so delightful? Let us know their names, and something of their lives and great deeds, that we may be grateful to them for the pleasure and benefits they have conferred upon us, and honour their memories!

8. Linnæus is one of those great men who have thus benefited mankind. There is no student of natural

history, that has not reason to be grateful to this celebrated man for the assistance he derives in his studies from the labours of the great naturalist. If he is a botanist, fond of roaming over the fields and green lanes, amongst the hills and streams—of gathering the wild flowers that strew his path, noticing their resemblances and differences, examining their structure, forms, colours, and the changes they undergo, of inquiring into their properties and uses, the situation in which each abounds, &c.—he must desire to know what has been ascertained by previous botanists regarding the various plants in which he is interested. He must provide himself with a "Flora"—that is a description of the plants of the country in which he carries on his botanising excursions. Then, by an easy method, he will be enabled to find out the name of any of the many thousand plants described in the Flora which he may have before him; just as a person who knows the alphabet of a language, can, by a dictionary, find out the place of any word, and thus ascertain its meaning. This alone is a great matter: the young botanist finds a flower which is quite new to him; he has no one by him to tell him its name or anything about it; it may be any one of several thousand plants described in his Flora: by the examination of the flower, he soon finds out which of all these is the plant in his hands, and so learns its name and gets access to an account of it.

9. Now there are nearly a hundred thousand different kinds (or species) of plants known; and of these there are numbers that are exceedingly like each other, and somewhat difficult to distinguish from one another: yet he will find each kind described in his book with wonderful precision, in a very few words, so that the description cannot apply to any other plant, and conveys to him information as to the leading characters and properties of the plant in question. If, instead of being a learner, he is an accomplished botanist, examining the plants of some unexplored country, and

finding plants which had not been previously known or described, by means of the systematic arrangement of known plants, he is enabled at once to refer the newly-discovered plant to its proper place in the system; and by means of his previous knowledge, and an examination of a few of the characters of the plant, he can form a pretty accurate judgment as to its internal structure, properties, and probable uses.

10. There is nothing more beautiful in the whole range of science than the admirable arrangement in scientific works of the vast number of objects which compose the animal, vegetable, and mineral kingdoms; and it is to Linnæus that we are chiefly indebted for the order, simplicity, and precision which now reign over this immense field of human knowledge. He was very early struck with the disorder and irregularity which prevailed throughout every department of natural history.

11. Although there were many learned works on various subjects of natural history, the different species* were not distinguished with precision from each other; there was no complete catalogue and description of them: such descriptions as were given were not drawn up on a uniform plan, nor were the terms employed in these descriptions well defined, so that mistakes and misunderstandings often arose: the methods in which the species were arranged were imperfect, inconvenient, or inaccurate, nor were the subdivisions systematically made, so that any object could at once be set in its proper place in the system; and there was no common understanding as to the names assigned to the species, which varied according to the fancy of each author, while some of these names were composed of so many words that no memory could retain them. All this, Linnæus set himself to reform.

* If a plant produce a great many seeds, all the plants grown from these seeds would be said to be of the same *species*, also all the plants grown from the seeds of the latter. The apple and pear are different species; they are like each other in the flower and fruit, but the seeds of one will not produce the other.

12. He adopted or devised methods of arrangement capable of including all the objects in which the characters of the various divisions and subdivisions were distinct and well marked, and the subdivisions of any order were founded on certain characters of similar organs, so that they might be readily contrasted. He devised or improved numbers of terms to express the prodigious varieties of conformation observed in the objects; he himself examined thousands of plants, animals, and minerals, and reviewed the descriptions of preceding naturalists, and then formed a descriptive catalogue of them arranged after his new methods, and accurately described by the terms he had defined; and, finally, he named them, giving to each species two names, one expressive of the tribe or sort (or genus) which it most resembled, and called its generic name, the other to distinguish that particular species, called the specific name.* This was an immense work: and this Linnæus did. His great merits were, as Cuvier remarks, the distinctness with which he pointed out and separated each species, the uniformity and exactness of his characters of genera, the care which he took in detailing all the variable circumstances, as size, form, colour, &c., the energetic precision of his technical language, and the extreme convenience of his nomenclature, the latter including the happy idea of designating each species by only one distinctive name, usually an adjective, called the trivial name, and which, joined to the generic name, should take place of the long sentences previously used.

13. Such was Linnæus' work, and while succeeding naturalists have been able to improve upon his system and extend it, it must be admitted that he laid the basis of those admirable methods of arrangement by

* Thus there are many species of the well-known buttercup or crowfoot, very like each other, so that careless observers do not distinguish them, but still with well-marked and permanent distinctions. Each is called Ranunculus (the generic name), and besides that the *specific* name expressive of some peculiarity, as *bulbosus* (bulbous) *acris*, *repens* (creeping), *aquatilis*, &c.

which the vast materials of natural history first acquired a scientific form.

14. Popularly, Linnæus has been best known by his famous system of classifying plants, depending mainly on the number and proportion of the stamens and pistils: an artificial method of arranging plants, which had some conveniences, and which in the absence of any better method, was very generally adopted. In the Floras of most countries, the plants were once arranged according to this method; but it has long been disused in France, and is now going out of use in this country.

15. With his usual happy genius for arrangement, Linnæus gave it great technical precision, and for the latter half of the last century, and first quarter of the present, his system was very popular, and may be said to have reigned supreme in botany. Having now, however, been almost superseded by better methods; and, indeed, even such as it was, not having been his own invention (though improved by him), it is unnecessary to dwell upon it: he has far higher claims to fame than the Linnæan system of classification, even had it been entirely his own.

16. In the year 1736, Linnæus visited England. He was not acquainted with the language, but, like most educated men of these times, he was able to speak Latin fluently. It has been said that he was not very well received by two of those who might have been expected to give the most cordial reception to a distinguished foreign naturalist—Sir Hans Sloane, and Dillenius, Professor of Botany in the University of Oxford. When he was introduced to the latter, he addressed him in Latin, apologising for his want of English, and Dillenius is said to have remarked to a bystander (not supposing that Linnæus would understand it), "This is the young man who would confound all botany," referring to the great changes he wished to introduce into the science. But although Linnæus did not understand English, he understood

Latin and men's looks, and "confound," being a word of Latin derivation, and set close beside the word "botany," he was enabled to make out his meaning, and afterwards, when they had become more intimate, referred to it. He soon after went to Paris, where he was kindly received by the celebrated French botanist, Bernard de Jussieu: it is interesting to know that these two great men, the first botanists of their age, met, conversed together, and enjoyed each other's society.

17. Linnæus having now acquired a great name, was patronised by men of influence in his own country. In the year 1738, having previously obtained the degree of doctor of medicine in Holland, he was appointed physician to the Swedish fleet. In 1741 he was appointed Professor of Medicine in the University of Upsal, and was soon enabled to exchange this for the professorship of botany, a chair which he filled upwards of thirty years. By his professorship and his practice as a physician, he soon acquired sufficient means: and being appreciated by his own countrymen as well as abroad, and enjoying an honourable and independent position, may be considered to have been amply compensated for the arduous struggles and anxieties of his early years; and stands forth a bright example of what may be accomplished, in spite of great obstacles and difficulties, by patient endurance, ardour, and perseverance. Remembering the difficulties he had himself to encounter when a student, he always refused to take fees from such students as he suspected could ill afford to pay them. In 1753 the king conferred upon him the order of the Polar Star, a distinguished Swedish order; and in 1756 he was ennobled. He was made an honorary member of many eminent foreign learned societies, and some foreign courts invited him to visit and settle beside them. But he would not leave his native country. Full of years and fame and honours, he died in the year 1778. He was buried in the cathedral of Upsal; and such was the

sense entertained of the national loss, that the king publicly referred to it in his address to the States of the kingdom.

18. Linnæus married, in the year 1740, the lady to whom he had become attached at Fahlun. They had four daughters, and a son who succeeded him in his professorship; but did not long survive him, dying in 1783. Then, the great and valuable collection of specimens which his father had made was sold, and bought by Sir James Edward Smith, a distinguished English botanist. The transaction was completed, and the collection shipped for England in a merchant vessel during the absence of the king. When he returned and found this valuable collection disposed of and carried out of the country, he viewed it as a national loss and disgrace, and sent a ship of war in chase of the merchantman, to bring her back with her precious cargo. But it was too late; the unrivalled collection safely reached its enterprising purchaser, and from him, in course of time, passed to the Linnæan Society of London, in whose possession it still remains.

JUSSIEU.

1. This is the name of a family of eminent botanists who flourished in France during the middle and close of the last century—consisting of three brothers and a nephew. Of these, two—namely, Bernard de Jussieu and his nephew Antoine Laurent de Jussieu—were pre-eminently distinguished as having first established on a scientific basis that method of arranging plants called the method of Natural Families.

2. Bernard de Jussieu was born at Lyons in the year 1699. In 1722 he was appointed botanical demonstrator at the *Jardin du Roi* (now the Jardin des Plantes) in Paris. In 1720 he had obtained the degree of doctor of medicine, with the view of practising the profession; and did engage in practice for a short time, but his too great sensibility made him feel acutely

the sufferings of his patients, and brought on palpitations which compelled him to renounce that profession. He was a modest, simple, earnest-minded man, inspired with an ardent love of natural science, especially botany. Some of his pupils occasionally took advantage of his good nature to practise little tricks upon him, such as confounding his specimens by removing parts and substituting those of totally different plants, thus making up imaginary plants of the most incongruous description—the leaves of one species and flowers of another, or of two or three species—hoping thus to puzzle and perplex their patient and good-humoured master. It is said that when Jussieu and Linnæus were making botanising excursions in the neighbourhood of Paris, accompanied by several of the pupils of the former, these mischievous youths brought their master such made-up specimens to show to his distinguished friend; but the acute eye and botanical skill of Jussieu were not baffled—he always detected the imposture. He communicated his ideas freely to his friends, and pupils, and even to strangers; sometimes his discoveries were appropriated by others and published as their own; and when told of such a plagiary, one day, he simply remarked—"Eh! well, what does it concern me, provided that it become known?"

3. In the year 1758 he was charged by Louis XV., then king of France, with the arrangement, in the royal garden at the Trianon, near Versailles, of a collection of the plants cultivated in that country. He arranged them according to the method of natural families; and the Catalogue de Trianon exhibited the first systematic classification of plants on that plan. Bernard de Jussieu enjoyed the favour of the king, who used to take great pleasure in his conversation; he was a member of the Academy of Sciences at Paris, and was highly esteemed by his associates; while his fame had spread also to foreign lands, and he was chosen an honorary associate of the great scientific societies of Berlin,

Petersburg, Upsal, and London. He died in 1777, having had the misfortune of being blind for some years previously; leaving to his nephew a rich inheritance in his great ideas.

4. Antoine Laurent de Jussieu, the nephew of Bernard, was born at Lyons in the year 1748. In 1765, he came to Paris and studied under the care of his uncle Bernard. In the year 1770 he was appointed botanical demonstrator at the *Jardin du Roi*, and in 1777 was placed at the head of the administration of that celebrated garden. He was much associated with his uncle, became impregnated with his ideas, and extended and improved them by his own genius. In 1789 he published his great work, *Genera Plantarum, secundum Ordines Naturales disposita* (The Genera of Plants, arranged according to their Natural Orders), and by this work, and his public lectures, contributed greatly to the introduction of the natural system of classification of plants. He died in the year 1836.

5. It had long been known that there were certain tribes or families of plants, the species of which, though different and distinct, still bore a great general resemblance to each other in form, structure, and properties. Thus, the rose tribe, the buttercup tribe, the cruciform tribe, the papilionaceous tribe, the umbelliferous tribe, the thistle tribe, were distinctly marked groups or natural families; but only a few of these natural families were known: there were numbers of plants not included in such divisions, and it was necessary that the system should be complete, so as to include all known plants, and provide easy admission for those which might subsequently be discovered. Also, it was desirable that these families themselves should be classified, or arranged in larger groups, according to the greater or less resemblance between them.

6. In the *natural* system, plants were placed together that resembled each other in the greatest number of important particulars; and when it was ascertained that a plant belonged to a certain natural family, much infor-

mation was at once obtained respecting its structure and properties. In an *artificial* system, such as the Linnæan system, plants were placed together which agreed in one point though they differed in every other, and had little natural affinity; while plants which were evidently of the same natural tribe, and resembled each other in most points, were separated if they did not agree in that one, chosen as the mark of distinction. Linnæus was well aware of the importance of the natural method, published a sketch or fragment of such a method, or list of natural families, and declared that to perfect that method should be the aim of botanists, and that the greatest honours should be paid to those who succeeded in so doing.

7. Bernard de Jussieu and his nephew pointed out the true principles of the system of natural families; and although the system has been much improved and extended by succeeding botanists, there can be no doubt that to them we owe the first exposition of the scientific principles of the natural method.

HUGO REID.

Animal Physiology.

BY JAMES MANN.

LESSON I.

THE MUSCLES AND NERVES.

"Whatsoever thy hand findeth to do, do it with thy might; for there is no work, nor device, nor knowledge, nor wisdom in the grave whither thou goest."

1. ANIMALS are able to perform movements of a peculiar kind whenever they please. They can change the natural position of different parts of their bodies, as a man does when he lifts his hand to his head; and they can carry their bodies from place to place, by the effort of their limbs, as quadrupeds do when they run along the ground, or birds when they fly through

the air. Ability to effect motion of this kind is one of the privileges of animal existence. Stones and plants cannot do it. A particular apparatus is planned, and laid down for the accomplishment of the purpose. Cords are stretched from one part of the body to another, and are so attached that those parts may be drawn nearer together, or may be pulled further asunder. These cords are named muscles.

2. Muscle, the cordage provided for working the mechanism of animal bodies, is familiarly known as flesh. Now when a piece of fleshy meat is closely examined, it is seen to be composed of a quantity of little fibres placed side by side, and tied up in bundles by delicate membranous films, that are rolled around them, as paper is sometimes rolled round a bundle of matches. The external film of the bundle may be torn off, and the several fibres composing it be separated from each other. Each then appears as a long, nearly cylindrical body, rather larger than the fibre of coarse sheep's wool. When one of these small fibres is taken from the rest and greatly magnified, by a powerful microscope, it becomes apparent that it is made of yet more minute threads laid together side by side. Each fibre contains some 600 of these diminutive threads. Four hundred of the fibres might be placed in contact with each other, within the breadth of an inch, but as many as ten thousand of the threads will lie in the same space! Such is the nature of muscular flesh. It is composed of innumerable threads, so fine that 600 of them would scarcely equal a thread of wool, bound up together in hundreds to make fibres, those fibres being then, in their turn, connected together into bundles. Fig. 1. is a magnified view of a piece of muscle, showing its composition of threads united into fibres, and of fibres into bundles.

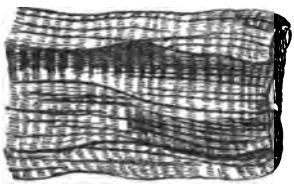


Fig. 1.

3. It will be observed, in the above sketch, that the bundles of muscular fibres are crossed by transverse lines. There is a very curious reason for this appearance, which has been recently discovered through the employment of microscopes of high excellence. Each diminutive thread in the fibre is a pile of small drum-shaped bodies placed end to end, and adhering together. It is the joining of these ends that causes the transverse markings. Each little drum is really a living cylindrical vesicle, flattened at top and bottom, and there made to stick to its neighbours. It possesses a distinct wall of its own, and is filled inside with a dark red substance, which is really the coloured nutritive liquid, prepared by the blood-corpuscles. The ultimate thread of muscular fibre is thus made of vesicles, connected together like a row of beads, and the fibre is a bundle of these beaded threads. Fig. 2, *a*, is a highly-magnified view of a muscle-thread, formed of vesicles piled end to end, and each containing within itself the dark, nutritive liquid, prepared for it by the corpuscles of the blood. Blood-vessels come into the muscles, are distributed amongst their fibres, and then send a close network of fine capillary tubes to branch about over the beaded vesicles. In this way an abundance of nourishment is supplied to the vesicles, but each vesicle is closed everywhere completely; nothing can get either into its cavity, or out therefrom, except by passing through its wall. The red blood liquid transudes through the coats of the vessels and also through that of the vesicle, to get into its appointed place.

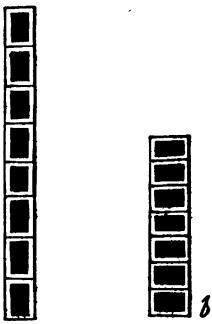


Fig. 2.

4. Muscle is thus really built up of vesicles, arranged in rows, as walls are built up of bricks arranged in rows. But these muscle-vesicles are distinguished from

all the other vesicles of the frame, by one remarkable character. They have the power of altering their dimensions, when influenced by certain inducements. All at once, they diminish their lengths by one half, and increase their breadths to the same amount. At *b*, Fig. 2, a muscular thread is shown in which this alteration of the dimensions of the component vesicles has taken place. Each vesicle is here as short again as it is at *a*, but it is also twice as broad.

5. It is possible to imagine that a wall, built of a given number of bricks, has all at once had the form of its several bricks altered, by a stroke of magic, in such a way that each becomes only half as long as it was before, but, at the same time, is swelled out until it was twice as broad or high. Now the result of such a change, provided all the bricks still hung together, would be that the wall also would diminish its length by one-half, and double its height. If it were before twelve feet long and six feet high, it would now become six feet long and twelve feet high. Such is really the effect produced, in the case of the muscular thread, when its vesicles change their form, for they still adhere firmly together. The thread swells out in breadth, but diminishes in length in a like degree.

6. It is in this way, then, that the muscles of the animal frame are worked. The vesicles of which their threads and fibres are built, are continually changing their dimensions, and so, first drawing in their lengths, and then shooting them out again. All the vesicles, in an acting muscle, do not, however, contract their dimensions at once. Some are drawing in their lengths in one place, while others are shooting theirs out in another. The contractions run through the muscular substance, very much as waves run over the face of the sea. These alternate contractions and expansions produce a rustling sound, which may be heard when the ear is placed over a powerful muscle, in energetic play.

7. There is one condition which is absolutely essential

to the continued activity of the muscular vesicles. They must be furnished with an abundant supply of florid, arterial blood. Dark, venous blood will not do. When such only is circulated, the muscles speedily lose all their contractile power, and get so thoroughly stupified, that their activities cannot be again aroused. The red corpuscle must be present, with its sustaining load. The muscular vesicle and its rich contents are destroyed by the contractile effort. The worn-out and waste material is taken into the blood, and carried off through the venous channels. New substance is, at the same time, built up out of the fresh plastic material that is brought, in the blood, through the arterial channels. The change in the form of the muscle-vesicle is, in some way, dependent on the destruction of its substance. Hence, all sustained muscular exertion is attended by exhaustion, and demands a continued supply of plastic nourishment. Muscles get fatigued from excessive action, on account of the principal part of their structure having been worn up, and they are refreshed by rest, because then an opportunity is afforded to the blood to restore the waste.

8. The muscles are thus ropes, that are able to originate motion, by diminishing their own lengths. The opposite extremities of the fibres are firmly attached to parts, that can be brought nearer together when pulled; then, whenever these fibres diminish their lengths, the parts to which they are fixed must move towards one another. Sometimes, the contractile fibres are so arranged that they work hinged levers, just as doors may be opened and closed by ropes attached to the handle. The jointed limbs perform their offices in this way. Occasionally the fibres pass over pulleys to change the direction of their operation. Very often they are spread out into thin sheets, and inserted into skin, or other forms of membrane, which they have to wrinkle and fold. Sometimes they are moulded into the form of rings, and interwoven amongst each other so as to compose a hollow bag. Then, when they contract their

dimensions they squeeze the contents of the bag out through its mouth. This is the manner in which the heart propels the blood. In many places, the fibres are arranged in circles, round openings left through the external skin. Then, when they shorten, the openings are closed. The mouth is compressed in this way, by muscular bands that are situated in the lips.

9. STRUCTURE AND USE OF THE NERVES.—The muscular apparatus would be of no use whatever to animals, unless they were provided with the power of directing and governing its operations. There would be no gain to them in being able to tumble about the world, if their tumblings were destitute of all purpose. Animals perceive the objects that are scattered around them, and then direct the movements of their frames in such a way, that they get to occupy certain intended positions amongst these objects. They avoid certain relations that would be injurious to their bodies, and they seek certain others that are advantageous to them. This power of perceiving external things, and of directing their muscular movements, by efforts of their wills, constitutes the great privilege of their existence. The functions of sensation, perception, and motion, indeed, make up between them, what is termed *animal life*, in contradistinction to the other kind of unsentient life, which only concerns itself with feeding and organising, and which therefore is denominated *organic life*. All vital organs, that belong neither to the moving, nor to the feeling and perceiving service of the economy, are merely subservient provisions, made to keep the higher faculties in working trim. But, of these higher faculties, that of mere motion is also, in a degree, inferior too; since it must be directed and guided, if it is to be used to any purpose. Hence, the one grand power of the economy, that to which all the rest minister, and that which constitutes the main distinction of animated being, is really perception, and the capacity to determine and direct the movements. This power has its own material mechanism and its apparatus. The

several pieces of mechanism, taken collectively, form what the physiologists term the *Nervous System.*

10. When the fibres that constitute the muscular bundles of flesh are loosened from each other, and closely observed, a vast number of delicate white strings are found to be looped about among them, hither and thither, in great abundance. In fig. 3, a representation is given of the appearance of these white strings amongst the muscular fibres, both being greatly magnified: *aa* are the white strings, and *bb* are the threads of the muscular fibres amongst which they are placed. Some of the larger of these white strings were noticed by the old Greek anatomists, and they called them by their name for string. This word was *neuron.* From *neuron*, the more modern physiologists have made the English word *nerve.* The white glistening strings, scattered about in various parts of the bodies of animals, are denominated *nerves*, and the system of living contrivances to which they belong, and of which they form an important portion, is from them designated the *nervous system.*

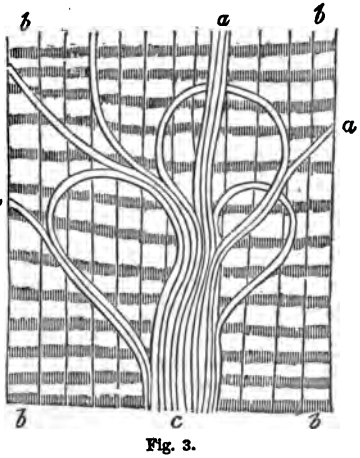


Fig. 3.

11. The white strings, that are scattered in loops among the muscular threads, are, however, not merely strings as they appear. They are really tubes. The appearance of a small portion of some of them, when immensely magnified, is represented in fig. 4. They are composed of sheaths of exquisitely-delicate mem-

brane, containing inside a soft pulpy substance. This is probably the nerve-substance, which is of such surpassing interest, on account of the intimate connection that exists between it and all the wonderful feeling, willing, and thinking faculties of the living creature. It is a very soft material, and contains considerably more water in its composition than any other structure in the body. It has in it six times more water than solid ingredient, a provision, no doubt, for favouring the rapid changes the substance is destined to undergo. It is also a very combustible material. One-half of its solid constituents are phosphorus and fat, both principles that are very prone to combine their elements with oxygen. In every fifty ounces of nerve-substance, one ounce is pure phosphorus, and forty ounces are pure water, and about five or six ounces are fat. The tubes, in which this combustible pulp is packed away, are of almost inconceivable fineness. They are of only half the thickness of the finest fibre spun by the silkworm. Some four thousand of them might be laid in contact, side by side, within the breadth of an inch.

12. The nerve-tubes, that are looped about amongst the threads of the muscles, get gathered together into bundles, as represented in figure 3, at *c*. In these bundles, the tubes lie side by side, and are bound up together by a common covering, but they never open into each other. Each one always remains a fine, closed pipe everywhere; (it cannot be said from end to end, because it has no end, being simply looped round as seen in the figure.) The nerve-bundles then run along in the muscular substance, uniting themselves in like manner with other bundles as they go, until larger and larger trunks are formed. These trunks take the most convenient course that offers to the nearest part of the back-bone, and there plunge through holes left in its sides for their reception, joining within the soft mass that lines it as a sort of marrow, and that is thence called the spinal marrow.

13. The nerve-tubes, then, really issue from the spinal

marrow, and are distributed throughout the body to the fibres of the muscles, each running to its own destination distinctly from its neighbours, although it is, for a long distance, bound up with them in the same general sheath. They loop about in the substance of these fibres, passing in amongst their beaded threads, and they carry to them a peculiar influence, which is the cause of their contractile movements. But the nerve-tubes do not anywhere open out into the little flattened cells of the muscles; the influence they transmit passes through the delicate walls of both tube and cell where those walls are placed in close contact. It is indeed so subtile that its presence has never been detected by direct means. It can neither be seen, nor touched, nor smelt. It is only recognised through its results. So long as the nerve-tubes are uninjured, the muscle supplied by them moves, whenever it is willed that it should do so. But if the nerve-tube is destroyed, in any part of its course between the spinal marrow and the muscle, no effort of will can make the muscle move.

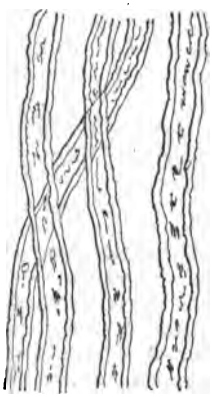


Fig. 4.

14. There is thus a very important and remarkable difference, between the method pursued in the distribution of blood vessels and nerves. Both come from central parts, and both issue forth from these, in trunks, and then divide into smaller and smaller branches, which are spread out all over the body, in looped or netted filaments. But the large trunk of a blood-vessel is a single capacious tube, continuous with all the branches it supplies. The blood that flows through it is scattered into its terminal capillaries, as water is scattered from a main, through the pipes that run to all the streets and houses of a town. While the large trunk of

a nerve is a bundle of separate tubes, each charged with the conveyance of a message of its own, and each carrying that message to its destination, irrespective of the presence of all the other tubes that lie in close neighbourhood. The arrangement of several of these nerve-tubes, in a common sheath, to form a nerve-trunk is shown in figure 5. In the blood-vessels, there is a true branching out of the interior space, because the design is the distribution of the contents of one channel in all directions. In the nerve-trunk, there is no branching out of interior space, because the object is, not the distribution of liquid substance in various directions, but the transmission of an influence along an immovable substance, from a given point to a given point. The submarine telegraph is intended to transmit electric signals across the sea. The several wires are twisted up into one cable, for convenience' sake, but they are kept perfectly apart within that cable, because each has its own message to transmit. Each wire is therefore packed away in a gutta-percha tube. Exactly the same arrangement is made, and for precisely the same reason, with the trunks of the nerves. Each filament of combustible pulp is ensheathed in an isolating tube, and these tubes are then bound into cable-like trunks. As each nerve-tube has to transmit its own signal, from the spinal cord to the exact muscular fibre that has to be moved, it would no more do to allow the nerve-tubes, in a trunk, to get in any way mingled together, than it would to allow the wires of the telegraphic cable to be confused with each other.

Fig. 5.

15. The delicate, glistening nerve-tubes are not, however, found only amidst the muscular fibres of the body. They are distributed, in equal abundance, over all its external surface. The skin is full of them; the cavities of the eyes, the ears, and the nose are completely lined

with them. These nerve-tubes also are gathered into bundles, and then these bundles are united with those that are connected with the muscles. The nerve-trunks that run into the spinal cord are composed partly of tubes that are distributed to the fibres of the muscles, and partly of tubes that come from the skin. Now both these sets of nerve-tubes transmit signals, but they differ materially in one essential point. Those in connection with the muscles, send the messages of the will outwards from the spinal cord to the apparatus of movement. But those in connection with the skin, send messages in to the spinal cord from the external parts of the frame. They communicate information regarding the conditions of surrounding things. The first are motor nerves, and transmit the commands of the will. The second are sensory nerves, and they carry the impressions of sensation. In both cases, the office of the tube is simply conveyance; nothing is originated in it. Influences communicated at one end are propagated along the pulp contained within the tube, somewhat as waves are propagated through pipes or canals of water, but the influence is very much more subtile than the wave.

16. The beautiful little nerve-tubes that hold the combustible pulp, and that transmit the orders of the will outwards from the central seat of animal life, and that carry the impressions of the sensations inwards to the same, are primarily made out of vesicles. Delicate round vesicles are first formed, which then lengthen out in opposite directions, until several meet in a line, and press against each other; next the parts, where the contact takes place, are removed, and so continuous channels are hollowed out, into which the nerve-pulp is poured. Vesicles may sometimes be seen, by the aid of the microscope, sending out tail-like little processes, as the first stage of their conversion into tubes.

LESSON II.

NERVOUS SYSTEM.

"Now hath God set the members every one of them in the body as it hath pleased Him."

1. *The Source of Nervous Influence.*—The nerve-tubes which are distributed to the skin and the muscles for the conveyance of impressions from the former, and of motor influence to the latter, all come out from the cavity of the backbone. They issue, indeed, from a mass of soft marrow, that fills up a canal, hollowed out through the entire length of the backbone, quite up into the skull. This spinal marrow, then, is the vital organ that receives information regarding the state of external things, and that issues orders for the movements which are to be performed. It is lodged in the hard, bony canal, that it may be carefully protected from harm, and it runs along the back that it may be conveniently placed for issuing nerve-tubes to all parts of the body. The backbone is formed of thirty ring-shaped pieces of bone, possessing somewhat the shape sketched in fig. 6, placed in a line, and firmly jointed together. At *o*, a large hole is seen hollowed out completely through the piece. When the thirty pieces are all fixed together in their proper relations, the holes constitute one continuous cavity, from end to end of the connected chain. It is in this that the spinal marrow is lodged. The top and bottom of each bony piece have also little notches grooved into them, one on either side. At *n*, *n*, the two upper notches are shown. When the upper and lower notches are applied to each other clear openings are left quite

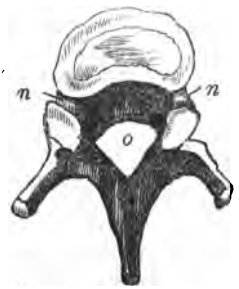


Fig. 6.

into the central canal. It is through these openings, pierced into the sides of the spinal canal, that the nerves pass to get into communication with the spinal marrow. There are thirty pieces of bone (besides three others that are without internal cavities), but there are thirty-one pairs of nerves, because an additional pair issues over the uppermost bony piece, between it and the skull.

2. The central part of the spinal marrow is formed of a soft, grey-coloured substance. This is surrounded by a thick coat of white matter. When the spinal marrow is cut across, the internal grey portion and the outer white portion are seen to be arranged as sketched in fig. 7. Now the outer whiter portion, when carefully examined, is found to be nothing else than bundles of nerve-tubes. A great number of the nerve-tubes are turned upwards as soon as they get inside of the spinal cavity, and are then bound altogether into one hollow bundle, or coat. It is in consequence of the appearance of this fibrous part that the spinal marrow is sometimes called the spinal cord.

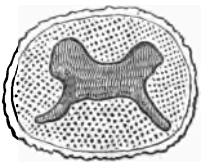


Fig. 7.

3. But the grey central part of the spinal cord, its true marrow, is made of an altogether different material. It is entirely composed of clusters of delicate vesicles, hanging about meshes of capillary blood-vessels, much as grapes hang about the stalks of the vine. But the vessels do not end in the vesicles, as the stalks do in the grapes. They form fine and thickly-meshed nets, and the vesicles are packed away amidst the meshes of these. The vesicles are filled with precisely the same kind of nerve-substance as the nerve-tubes. The grey colour of the mass is entirely due to the blood that circulates freely amidst them, through the capillary meshes of the vessels. Its red colour, seen through the half-transparent white substance it lies in the midst of, assumes the softened hue of grey.

4. There are thus, then, two distinct forms of element in the nervous apparatus. There are fine long membranous tubes, filled with a white pulpy substance, and there are delicate membranous vesicles filled with the same material, and grouped around and in, the abundant meshes of capillary blood-vessels. The tubes are merely channels provided for the conveyance of an influence. The results of changes, commenced beyond their extremities, are propagated somewhat after the manner in which waves are propagated through channels of water. But the vesicles have a far higher office to perform, as might be at once inferred from the vast supply of blood that is sent to them. They originate the influence which the nerves convey—they secrete it from the blood, so to speak, and send it streaming down the tubes. Nerve-vesicles are mostly of very much larger dimensions than nerve-tubes. But the latter are always found passing in amidst the clustered masses of the former. Fig. 8 is a magnified view of the clustered nerve-vesicles, with the tubes passing in amongst them. The tubes and vesicles never open out into each other, any more than the vesicles and blood-vessels do. The nerve-substance that is formed out of the blood by the vesicles transudes through the closely-conjoined delicate walls of the vessels and vesicles: and, in the same way, the nerve-influence, that is produced in the vesicles, passes through the conjoined walls of the vesicles and nerve-tubes to get into the interior of the latter. Whenever nerve-vesicles are placed in the course of nerve-tubes, they are arranged into little knotty clusters. Hence, they have come to be called *ganglia*, from the Greek name for peculiar kinds of swellings that they were once conceived to resemble. In general language, the collected bundles of nerve-tubes, as well as their isolated and looped continuations, are termed *nerves*, and the clustered masses

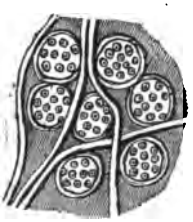


Fig. 8.

of nerve-tubes and nerve-vesicles are designated *nervous ganglia.*

5. In the spinal marrow the nerve-vesicles that originate nervous influence, are placed in a long-connected cluster within an outer covering of nerve-tubes. These latter, however, are not the tubes that really belong to the spinal ganglia. They go up to the brain to establish communications with it. Some of the nerve-tubes that come into the spinal cavity, through the small side openings left between the several pieces of the back-bone, pass at once into the midst of the grey, central ganglionic mass. These are the tubes that bring impressions *to the spinal marrow*, and that carry back *from it* directions for muscular movement. The two different classes of nerve-tubes are bound up together, so long as they form the nerve-trunk; but directly this has entered the cavity of the spinal canal they get sorted out from each other, and take separate paths. The tubes that bring in impressions to the spinal marrow go backwards, and pass into its substance through a little cleft. But those which convey outwards the motor directions, go forwards, and enter by another fissure there. Each nerve has thus two roots; a back one formed of sensory, or inward carrying-tubes, and a front one of motor, or outward carrying-tubes. In fig. 9, all this is represented. A portion of the spinal marrow is there drawn, with its side forwards, and *n* is a nerve-trunk that has just entered through one of the small openings of the bony canal. *f*, is the front root, composed of motor tubes, and *b*, is the backward root of sensory tubes. On the top, cut surface, the central,

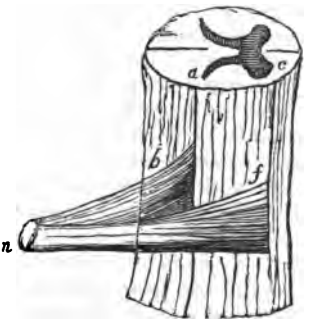


Fig. 9.

grey ganglionic mass is seen at *a*, sending backward a narrow slip of its clustering vesicles to meet the sensory tubes, which may be traced passing quite in among them. At *c*, a similar strip is seen advancing forwards to meet the motor tubes.

6. The nerve-tubes, which convey external impressions inwards to the central nervous ganglia, are looped about everywhere upon the surface of the body. The skin and the organs of sense are full of their terminations. But nerve-tubes cannot originate impressions any more than they can impulses of movement. Wherever influence is to be set up, nerve-vesicles and capillary blood-vessels must be. Hence, all the external terminations of the sensory tubes have their layers and clusters of grey substance intermingled with them—nerve-vesicles and their supplying vessels are found in the papillæ of the skin—in the tongue—in the nose—in the eyes, and the ears. The organs of the external senses are, indeed, superficial nerve-ganglia, with their apparatus of conveying-tubes, just as the spinal marrow and its continuation are central ganglia. The organs of the senses originate sensations and impressions, when they are stimulated by certain agents, and send these into the central nerve-masses. The central nerve-masses originate motor impulses, when subjected to certain stimulant influences, and transmit them to the apparatus of muscular fibres that is expectantly distributed around.

7. UNCONSCIOUS ACTIONS AND INSTINCT.—The spinal ganglia are, then, a connected cluster of nerve-vesicles, furnished with an apparatus of fine tubes, distributed to all parts of the body, and endowed with the capacity of receiving and recognizing certain messages, sent in through these tubes, and of then responding to these messages, by issuing orders of their own through them to the muscles. All this work of the spinal ganglia is, however, transacted unconsciously. It goes on day and night, but the individual feels nothing of it. The impressions conveyed into the spinal marrow, through the nerve-tubes, are therefore not properly sensations;

they are merely unsentient impressions. The sensations go to a higher department of the nervous system. They are carried up, through the tubes that form the white investment of the spinal marrow, to an office provided above for their reception and registration. The spinal ganglia originate movements, that have nothing whatever to do with the influence of consciousness, or the will. They do so, in consequence of certain impressions that are communicated to them; but these impressions immediately call up the movements that follow them, without any intermediate stage of sensation, perception, or voluntary determination being first produced.

8. The especial business of the spinal ganglia is to watch over the performance of certain operations that are essential to life, but that could not have been intrusted to the care of the will and the higher mental faculties, because these all take periodic naps, and are thence, at times, unqualified for the trust. Thus respiration is necessary to the maintenance of life. It cannot be arrested for even a few minutes, without death ensuing. But respiration is not a voluntary act, or it would stop during sleep. The breathing is kept up unconsciously, and this is effected by the instrumentality of the spinal ganglia. Nerve-tubes run from the chest to these ganglia, and the air, as it passes through the lungs, makes a certain impression upon the outer extremities of the tubes, which impressions are then propagated inwards to the ganglia, and immediately call forth in them the impulses that are returned to the muscles of the chest, as directions to contract their fibres.

9. All involuntary actions that are insensibly performed, like the breathing, are carried on under the direction and control of the spinal marrow. It is the watchful guardian of life, whose care is quicker than thought. When an insect approaches the sensitive eye, the spinal marrow shuts down its lid, with a wink; when any foreign object attempts to insinuate itself into

the windpipe, it is the spinal marrow that expels the intruder, with a cough; when irritating substances lodge in the nose, it is the spinal marrow that dismisses them, by a sneeze. When bland and wholesome nourishment is lodged in the stomach, the spinal marrow directs its digestion, and its conveyance onwards in the intestinal tube, but if the substance prove to be poisonous or harmful, instead of bland and nutritious, the spinal marrow immediately reverses the order of things, and ejects the dangerous visitant. Hiccup, sighing, yawning, laughing and crying are all illustrations of actions performed involuntarily, under the mere influence of irritation, propagated to the spinal ganglia, through the incarrying nerve-tubes, and then sent back from the ganglia to the muscles concerned in the performance of the actions, without having been allowed to penetrate further into the recesses of the nervous shrines. These actions can, however, be also instituted by the will.

10. In the highly-organized animals, and especially in those of the human kind, the spinal ganglia form but a subordinate portion of the central nervous system. But there are more lowly creatures, which are endowed with no higher development of nervous mechanism. In such animals, the ganglia are not lodged in a bony case, because there is no hard internal skeleton furnished, that could afford such a retreat. They are merely arranged in a double row that runs along the body in the midst of the other soft organs. Such animals swallow their food when it touches their mouths, withdraw themselves from injurious influences, and also digest, grow, and multiply their forms, but they seem to be devoid of all traces of sensation, or consciousness. They are little more than plants, that are capable of performing certain movements, under the application of external excitements, as well as of growing. All the organic functions of animal existence are duly performed, where there is no other guide for their accomplishment than the operations of the spinal ganglia. Hence these

ganglia may be looked upon as being the appointed guardians of organic life.

11. The spinal marrow runs up through the hollow channel lying within the backbone, and projects above some little distance into the cavity of the skull. The nerve-tubes, which form its white, outer coat, there come into communication with a mass of nerve-vesicles which constitute a distinct cluster of ganglia, situated at the bottom of the brain. These ganglia are shown at *s* in figure 10, *m* being the spinal marrow that comes up from the cavity of the backbone, to pass on into them. All those nerve-tubes that convey inwards the impressions of sensations, and that help to compose the spinal nerves while doing so, are continued upwards along the outer surface of the spinal marrow, and mingle at last with the vesicles of these upper ganglia. The nerves of special sense, those namely of the eyes, ears, nose, and tongue, go into them directly. The face, indeed, is chiefly a framework fixed directly beneath this part of the brain at *f*, for the convenient distribution of these sensory nerves.

12. The nerve-tubes that carry out motor impulses, which have been called up by the influence of sensations, issue too from these ganglionic masses. They constitute indeed, the great centre to which all sensations are conveyed, and from which all conscious movements are propagated. They are the seat of conscious and sentient life, as the spinal marrow is the seat of unconscious and involuntary

Fig. 10.

power. They are hence termed the sensory ganglia. Of all the vast host of nerve-tubes that are gathered in from the different parts of the system, a portion stops amidst the vesicles of the spinal marrow, but another portion goes on along the outer surface of the spinal marrow on to the sensory ganglia placed at its top. The first call forth involuntary and unconscious movements; the second those that are conscious, but still not voluntary. The actions over which the sensory ganglia preside are all unvarying operations, always performed in the same way, under the operation of the same stimulus, and are incapable of being altered by the will of the individual. Such actions are called *instinctive*, the word being derived from a Latin term that signifies to stir up, or provoke. Instinct is the impulse which stirs up living creatures to do certain things, irrespective of any recognition of the purpose for which such operations are performed.

LESSON III.

INSTINCT AND INTELLECT.

"Then, said I, wisdom is better than strength."

1. There are certain tribes of animals which exercise a great amount of ingenuity in providing for their daily wants, but which seem to be nevertheless perfectly unable to depart, by a hair's breadth, from a fixed routine. They evidently feel, for they draw back when they are hurt, and they have eyes, tongues, and other special organs of sensation. But they do not appear to be able to make any effort of will for the direction of their doings. No choice is allowed them in their operations. They cannot be trained or educated, and they are as skilful in their earliest infancy as after long years of experience in their crafts. They set about their business as systematically and as perfectly the moment they commence their existence, as they do in the full maturity of their years. They exhibit no diversity of character among them-

selves. Every individual of the species is exactly like its neighbours in all essential particulars.

2. Insects afford the most striking illustrations of this kind of regulated existence. When the proper moment has arrived for the young bee to make its entrance into the world, it breaks through the waxen walls of the prison-cell in which it has been nursed. Immediately on emerging from this, it begins to vibrate its newly-acquired wings, and to crawl restlessly about, until it reaches the outer door of the hive. Thence, it dashes forth on its first bold flight, but very soon, while soaring through the air, the fragrance of some neighbouring flower strikes upon its sense. Forthwith its rapid progress is arrested; it buzzes round the odorous attraction for an instant, then lights upon it, unfolds its tongue, darts the adhesive organ between the stamens and petals, and scrapes off the honey with which the various surfaces are bedewed. This the thrifty little collector then conveys backwards into its mouth, and finally deposits in its honey-bag. Having visited flower after flower, and gathered as much of the sweet substance as its receptacle will hold, the bee completes its freight by brushing off quantities of the pollen-dust from the anthers of the flowers, stowing away this portion of the cargo in the baskets attached to its thighs. With its bag of honey and its load of bee-bread, the insect then rises lightly into the air, and starts off for the hive that it recently left for the first time, in a line as direct as if it were a permanent railway laid down, for the direction of its course through the transparent atmosphere. Once again at home, the bee disposes of its hoard, either by feeding some of the busy workmen of the labouring community, or by storing it away for future use in one of the empty cells, and then thrusts its head and neck into another of them and refreshes itself with a quiet nap, before starting upon another cruize to the garden or the field.

3. Now, when the little busy bee makes its first start in laborious life, it has had no opportunity afforded it

of learning the details of the work it is about to perform. It has watched no older bee engaged in the same occupation. It has received no lessons regarding the use of spiral tongues and honey-bags. It has witnessed no exhibition of the convenience of leg-brushes and thigh-baskets. When it made its first bold dash from the door of its hive it had never even seen a flower, and yet notwithstanding all this, it proceeded at once, under the simple guidance of its senses, to the appropriate field of its avocations, and entered upon them with unerring skill. The power which impelled it, acted therefore independently of observation, experience, or instruction. This power was, indeed, a primary and intuitive impulse, dependent solely upon the creature's organisation; and it is this intuitive impulse which drives the living creature, independently of all acquisition through experience, observation, or instruction, to do certain things, that is designated, for distinction's sake, instinct.

4. Insects are singularly interesting objects to the observant student of nature, because in their bodies, the several elements of animal life are kept apart, which are more confused and mingled together in the higher creatures. Their designation is taken from the fact, that their bodies are divided or "cut" into several distinct parts. In perfect insects, there are three distinct segments, which are called the head, the chest, and the abdomen; of these, the hindermost division, the abdomen, is entirely devoted to mere nutrient offices; it contains the stomach and the digestive apparatus. The middle division, the thorax, belongs exclusively to the motor department; to it are fixed three pairs of nimble legs and two pairs of vigorous wings, with the muscular cordage requisite for the working of this mechanism. The head is the seat of sensation: in it are placed the eyes, the tongue, and the feelers, which take at once the position of fingers and ears. Now the insect has no back-bone, consequently it has no spinal marrow. But the ganglia of nerve-vesicles that correspond therewith

are present: they are ranged along the entire extent of the body in connected pairs; the last of these pairs is seated in the head, and receives the nerves of sense from the eyes, mouth, and feelers. There are, indeed, the sensory ganglia, that rule over the conscious although involuntary actions of the creature. The insect, however, has no nervous ganglia of any higher order than this. It is simply a piece of sensory apparatus, fed by digestive organs, and carried about by legs and wings; and it is hence the simplest and best illustration nature furnishes of simple instinctive life.

5. If the proceedings of the lower kinds of creatures are carefully noted, it will be observed that every action is directed to one main object, the preservation and extension of the individual's life. The spider threads her web that she may trap the fly on which she feeds. The silkworm spins her thread that her existence may be preserved with the silken walls, when her sentinel senses are wrapt in the chrysalis-sleep. The bee collects honey, and secretes wax, and the wasp pilfers sugar and manufactures paper, in order that collective bee-life and wasp-life may be comfortably sustained. As a general rule, the lower animals have nothing else to do, but to live and reproduce their kind: in them, life is the end, instead of being only a means to an end. Hence as the life of each individual of a species is the same, all the individuals are precisely alike. Even the old do not differ from the young in any perceptible degree.

6. If wasp after wasp be noticed as they enter the open window of a room, or bee after bee be scrutinized as they issue from the doorway of their hive, it will be found impossible to distinguish one of the winged fraternity from the rest. Every wasp will make the same angry dash at the observer, if he ventures to interfere with its predatory proceedings; every bee will be alike indifferent to the observer's presence, and will move on upon its busy task, provided he only just keeps himself out of its high road. Nature does not make some wasps jovial and generous, and others cunning and ferocious, as she

does with men. Neither does she distinguish clever bees from stupid ones, as she does with boys. So again, butterfly infants, and butterfly sages, are precisely alike in her hands; she institutes no mark of discrimination between them; all have no other task to perform than to take care of their lives, and life is the same in all. Hence uniform impulses are given to be the creature's guardian and guide, and these impulses are unvarying from birth until death, and are presented in precisely the same aspects as numbers are multiplied, so long as the character of the organisation, and the habits of life remain the same. The spinal marrow, and the sensory ganglia, combine their efforts for the safeguard of the creature; the only difference between them is, that the former watches over the several functions of the system individually, and works by unconscious impulses, whilst the latter keeps guard over the actions which the entire body performs as a whole, and consciously.

7. INTELLECT, AND THE OBJECT OF EDUCATION.—In insects, and in other animals of a like lowly organisation, every movement is an act either of emotion, or of passion, and the sensory ganglia are the organs that take charge of these instructive operations; man, too, has his emotions and passions, called up by the direct influence of sensations, mere instincts operating through the instrumentality of the sensory ganglia. But men do not generally allow their actions to be determined by impulses alone. They govern, control, and direct their emotions and passions, by a series of higher faculties, which are the noblest endowments of human existence. These faculties are classed together as reason and intellect. Now the reason and the intellect have their appointed seats in the wonderful mechanism of the body, as much as the unconscious, and conscious, but involuntary, operations.

8. Above the sensory ganglia, which are situated at the top of the spinal marrow, there are placed great clustered masses of nerve-vesicles, which receive myriads of nerve-tubes up into them from the spinal marrow,

and from the sensory ganglia. These constitute the *intellectual ganglia*, and it is through their agency that all the operations, which involve processes of reasoning, reflection, and judgment, and the exercise of will, are carried on. In figure 10, *c* indicates the position of the intellectual ganglia, above the sensory ganglia (*s*). The intellectual and sensory ganglia are placed together, and are contained in one common covering or bag, hence they are spoken of in ordinary language, as constituting a single organ, which is named the brain, a word derived from an old Saxon term. Animals that are governed entirely by instinct, have no intellectual ganglia, not even the most rudimentary trace. Other creatures that possess some of the powers of reason, such as memory, but in a very inferior degree to man, have small intellectual ganglia. In man, these ganglia are very large. From all this it is apparent, that the intellectual organs are not essential parts of the animal frame, they are superadditions, made to it, for purposes that are of a higher kind than any of those that are answered by animal life, viewed in the abstract sense.

9. In the rational creature, man, the intellectual ganglia form by far the larger portion of the brain. They consist of a vast mass of nervous substance, spread out as a broad thin plate, and then crumpled up into folds, and whelmed over in the sensory ganglia, so that these are nearly enveloped and lost sight of in the folds. This arrangement is made in order that the brain may be able to be packed away in the strong bony casket, or skull, provided for its reception, notwithstanding its enormous size. The folds, or convolutions, as they are called, of the intellectual ganglia of the brain, are represented at *c*, in fig. 10. These folds are composed of bundles of nerve-tubes within, some of them being prolongations upwards of the tubes of the spinal cord, and those of the sensory ganglia, and others being merely stretched across this way and that, from side to side and from place to place, in the mass. Over the ends of these tubes is extended a layer of grey-coloured

substance, made up of nerve-vesicles clustered together upon meshes of blood-vessels. The vessels are sent down in numerous branches from a vascular covering, that rests upon the brain-mass as a sort of coat. In the spinal and sensory ganglia, the grey vesicular substance is placed within a sheath of white tube-substance, because this has to be prolonged upwards into the higher organs. But there is nothing above the intellectual ganglia, consequently the nerve-tubes end in its substance, and the grey vesicular matter covers their ends as an outer investment. The tubes that run downwards from beneath the cerebral convolutions, bring the intellectual ganglia into a communication with the ganglia of the unconscious and instinctive operations. Those that run from place to place in the convolutions bring one part of the vesicular substance into communication with other parts, and, in this way, carry on the work of comparing, associating, and weighing. The intellectual ganglia of the brain constitute the organ which perceives the impressions of sensation, converts them into ideas, associates and arranges these ideas, and then, under their influence, originates the higher operations of the intellect, and the determinations of the will.

10. Every emotional impulse is attended by the destruction of a portion of the nerve-substance of the sensory ganglia. Every mental operation is connected with the destruction of a portion of the nerve-substance of the convolutions of the brain. Hence, blood must circulate freely through the brain, so long as these functions are to be kept in an active state; in the first place, to re-supply the material that has been destroyed, and, in the second place, to remove the waste product of the exertion. The great quantity of blood that is furnished to the brain of man, affords a beautiful illustration of the importance of the organ in the human economy, and of the extent of the influence reason is designed to exercise in human affairs. The human brain weighs about a thirty-sixth part of the whole human body, but this thirty-

sixth part of the frame receives no less a share than a *fifth part* of the entire circulating stream.

11. It is in consequence of the great preponderance of the convoluted portion of his brain, over the other originating portions of the nervous system, that man is so eminently a reasoning creature. In fishes, the sensory ganglia alone are larger than the intellectual ganglia; but in man, the intellectual ganglia are eight times more bulky than the spinal and sensory ganglia taken together. Hence, in man, every acting organ of the frame is kept in strict subserviency to the rule of intellect.

12. The nervous centres are threefold;—there is the lower department, that concerns itself with the business of unconscious life; the upper department, that takes note of sensations; and the supreme department, that is the seat of ideas: nerve-tubes run into all these departments from the outer surface of the body. Those that stop in the first department excite unconscious movements; those that go on to the second rouse sensations; and those that pass on to the third, originate ideas and trains of thought, and the exercise of will. As a general rule, every impression that is made upon the external extremities of the nerves, is transmitted to the furthest link of the nervous chain, and calls up at once an excited movement, a sensation, and a perception, or idea. These ideas are then consequently caused to blend with the unconscious movements and the sensations, and the will, that is aroused through them, fixes the course of action that is to be pursued. It is only when the impressions are stopped on the way, and prevented from passing onwards beyond the spinal or sensory ganglia, that the movements performed are really unconscious or instinctive, and devoid of all influence of will.

13. There is one important peculiarity in the operations of the intellectual ganglia. They are not essential to the maintenance of the life of the individual, and therefore they are not perfect from the first, like the

instinctive actions. They are very imperfect in the beginning, and then get strengthened and matured by exercise, and they seem to be almost indefinite in their powers of extension. The more men know, the more they seem to be able to acquire. But all their knowledge comes to them, through application and the exercise of thought. The intellectual faculties need to be trained. In every case they do get trained in a certain degree by accident, but it is only when they are designedly and skilfully trained that their full capabilities are brought into play. This, then, is the great object of education, the "leading out" of the faculties of the mind, and the placing of the actions under their control, in the stead of their being left under the influence of passion and impulse. Education replaces instinct by reason and a regulated will. It is entirely addressed to the intellectual ganglia. By its means these nervous masses are made more active, and consequently more influential in the actions of the economy. Many men have very large and fine brains, and yet make lamentably little use of them, because they have not been taught to do so. Others possess small brains and yet cause them to perform very serviceable work.

14. The will acts in two different ways. It directs and controls the movements of the body, and keeps these in accordance with principles that have been adopted, and resolutions that have been formed. But it also arranges and modifies the currents of the thoughts, and causes them to be subservient to the performance of the higher mental operations, and to the development of the judgment. Education should always have for its chief aim the making the will operative in this direction. It should steadily keep in view the formation of habits of patient and fixed attention, of clear and precise thoughts, and of slow and cautious judgment. Too often, while professing great things, it does little or nothing of all this. Many men who are deemed highly educated, are perfectly unable to confine their attention to the matter before them, to form precise ideas, or to

discriminate between their desires and their judgments. When the rational creature, man, is really well and highly-educated, he should be equal to the performance of the following operations of reason. He should be able—

1. To concentrate his attention at will, and to sustain its efforts.

2. To form clear and precise ideas.

3. To use words that exactly represent and define those ideas.

4. To arrive at his conclusions slowly and cautiously, suspending his judgment until all correlative facts are known, and maturely weighed.

5. To hold his conclusions as probabilities rather than as certainties, until they have been surely proved. And—

6. Above all, to be suspicious of his own inclinations and desires, and never to confound them with the conclusions of judgment, or to allow them to influence his actions, until reason is convinced they are right.

JAMES MANN.

Natural History.

BY GEORGE J. ALLMAN.

LESSON I.

PRINCIPLES OF PHILOSOPHIC CLASSIFICATION.

"And out of the ground the Lord God formed every beast of the field, and every fowl of the air; and brought them unto Adam to see what he would call them: and whatsoever Adam called every living creature that was the name thereof."

1. NECESSITY OF CLASSIFICATION.—When we reflect on the infinitely-varied structure of our globe—when we see that instead of uniformity of surface it presents us with an endless diversity of physical conformation—with mountains and plains, with fertile valleys and arid deserts, with rivers, and lakes, and fens, and the great

ocean flowing round them all—when we find the atmosphere itself, no less than the surface of the earth, diversified by ever-varying degrees of heat and light, and moisture and motion—it cannot strike us as strange that those living beings which crowd upon the land, or swarm in the waters, or in the air, should present a similar diversity, for we perceive how wonderfully their Creator has adapted them to their material dwelling-place, and we know that their forms must therefore vary with the multitudinous conditions which surround them.

2. To acquire an adequate knowledge of this mighty host of living forms is the aim of the biologist. But how is he to set about it? He attempts to study them *individually*, and form after form throng incessantly upon him: no necessary relation shows itself between the innumerable objects of his attention: he finds himself lost in a wilderness of isolated shapes and disconnected phenomena, he sees that to obtain a complete knowledge of any one, a lifetime would be needed, how then can he expect to become acquainted with the millions which surround him? He tries to study them in *masses*, but finds he can make no general assertions of his ill-assorted groups; difficulty crowds upon difficulty; he becomes disheartened in the labour which is before him, and gives up the study of nature in despair.

Such would assuredly be the fate of the naturalist; and our knowledge of the animal and vegetable tenants of the globe would never have advanced a single step beyond its condition in the infancy of science, were it not that two great agents in the study of nature come to his assistance. The two powerful auxiliaries which thus offer themselves to the naturalist are *Classification* and *Nomenclature*; by their aid the difficulties which beset the path of the inquirer rapidly disappear, order becomes everywhere apparent, and the great scheme of the material creation, instead of appearing as a confused mass of disconnected facts, opens up before him as one beautiful harmonious whole.

3. CONSTRUCTION, SUBORDINATION, AND ARRANGEMENT OF GROUPS.—Classification, as employed in the scientific investigations of the naturalist, consists essentially in the grouping of objects into assemblages of various degrees of generality, and the arranging of these groups in accordance with some fixed principle.

Three distinct elements thus enter into every philosophic classification, namely, *grouping*, *subordination*, or gradation of generality, and *arrangement*; and we shall now proceed to consider each of these as it presents itself in the philosophical classifications of the zoologist.

4. (1.) *Grouping.*—The objects to be classified are grouped according to their mutual resemblances and differences, so that all objects contained in any one group resemble each other more than they resemble any which are not contained in that group.

Now, although there is no property of objects which may not be made the foundation of the classification of these objects, it is yet by no means a matter of indifference what properties we assume as the basis of such a classification as is intended to become an instrument for the investigation of nature. The groups which will best serve the end of a philosophic classification are such as will admit of the greatest number of general propositions, and of the greatest importance, being asserted in common of all the objects contained in the group. The properties, therefore, on which the groups are founded, should be both numerous and important; they should be such as contribute most to make the objects grouped together like one another and unlike all other objects, such, moreover, as indicate the natural affinities of the objects, and cause each group to contain objects having closer affinities to one another than to those of any other group.

5. When these properties are also the most obvious ones, such as cause the objects to resemble one another, or differ from one another in their *general aspect*, they are the very best which can be chosen for the purpose. The great group of *Vertebrata*, for instance, is founded

on the presence of a vertebral column or backbone, which more or less determines the entire shape of the

PANTHER.

Fig. 1.*

animal. Now, as we shall afterwards more particularly see, we possess in this vertebrate character properties of great importance — properties which are particularly valuable, because they are at the same time *obvious*, and confer a peculiar and at once easily recognizable aspect on the object. But it by no means necessarily happens that the most obvious properties are also the most important; things may be very like one another in external form, and yet may be in their nature so totally different as to render it impossible to place them in juxtaposition without violating the essential rule of a classificatory group. The unobvious properties of objects are often therefore more important than the obvious, and should then form the basis of the classification; but when this is the case, some more easily recognizable properties coexisting with the less obvious ones should also be used as exponents of those more recondite, though more important, properties on which the classification is really based; otherwise we would be reduced to the absurd necessity of having to dissect every animal before we could place it in its proper group.

* Most of the figures introduced into the present article are borrowed from the well-known "Cours Elémentaire de Zoologie" of M. Milne-Edwards.

6. Thus the obvious external characters of a dolphin would never of themselves lead the zoologist to place it in the group of mammals rather than in that of fishes; dissection, however, proves it to possess lungs, a quadrilocular heart, mammary glands, and all the other essential characters of a mammal. The zoologist, therefore, does not hesitate notwithstanding its external fish-like form, to associate it with the ox and dog by placing it in the great group of mammals; and then seeking for some external marks which might in future save him from having recourse to dissection, in order to avoid the error of placing a dolphin among fishes, he finds these in the horizontal tail, in the blow-hole, in the teeth, and in other easily-recognizable characters, which will henceforth serve as indices of internal structure.

7. But it sometimes happens that the examination of the entire structure, internal, as well as external, of an animal in *any one period* of its existence, will not of itself enable us to discover those important properties which determine its association with one set of animals, rather than with another. It must be borne in mind that every animal possesses an extension in *time* as well as in *space*, and the same animal will frequently present very different characters, during different periods of its life. In order, therefore, to determine the proper associates of any particular animal in our classification, it will often be necessary to compare the whole series of forms through which this animal passes, in its progress to its adult state, with the corresponding series through which other animals pass; for often in this way only can we discover the important resemblances which constitute natural affinity, and upon which every group in a philosophic classification must be based.

An example will render this more obvious. The *Lernæa* and its kindred forms constitute a very singular tribe of animals, of uncouth shape and sluggish movements, living parasitically on fishes. Until very lately zoologists knew nothing of these creatures beyond the characters presented by them in their adult state: the result

was that their affinities were totally misunderstood, and in the various classifications, they were associated with animals, with which they had little or no relation. At

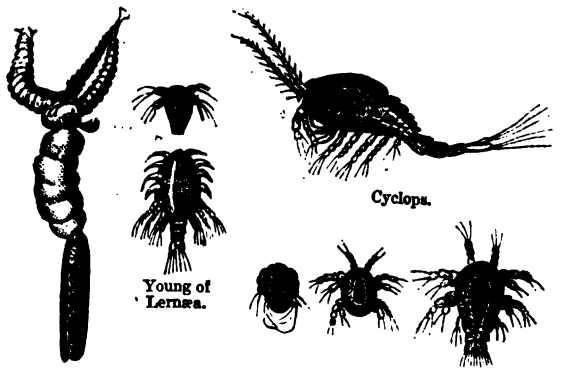


Fig. 2.

last, however, their *development* began to be attended to, and naturalists discovered the unexpected fact that just after escaping from the egg, they are in the form of free-swimming active little animals, so closely resembling the young of the *Cyclops*, and of some other of the lower forms of *Crustacea*, as to render it certain that their true affinities are with these. In consequence of this discovery they are now associated in a philosophic classification with the more simply-organized *Crustacea*.

8. (2.) *Subordination of Groups.*—The simple grouping of objects in accordance with their mutual resemblances and differences, though the basis of all classification is still very far from being all that is needed for the purposes of scientific investigation; the subordination of these groups constitutes one of the most striking and important features of a philosophic classification. The idea involved in the subordination of groups, is that of a graduated scale of comprehensive-

ness; for as individuals are capable of being associated into groups of the lowest degree of comprehensiveness, the "infima species" of the logicians, so these groups may themselves be collected into a smaller number of others of higher comprehensiveness, and these again into others still more comprehensive, and the same process may be thus continued until we arrive at the most comprehensive group, that which would correspond with the "summum genus" of the logicians, and which will, therefore, include all the others.

9. In the classification of the animal kingdom, six great steps of subordination are generally used. The lowest of these, that which possesses least generality is called the *species*. It is simply composed of *individuals*, and consists of all such individual animals as have descended from a common parent stock, or at least of such as resemble one another so closely as to justify us in assuming for them the possibility of a common parentage.

Thus all the individuals which possess the characters we meet with in the common ox, resemble one another so closely as to render it quite conceivable for them to have descended from one original pair; we therefore separate them from all other animals, and unite them into a single species. In the same way, the common sheep, the goat, the stag, the giraffe, and the camel, all represent so many distinct species.

10. But we soon perceive that the differences by which the several specific groups are separated from one another are by no means equal; for while some species are separated by strongly-marked differences, the differences between others are but slight; and this fact enables us to extend the principle of grouping, and to apply it to the species themselves, as we formerly did to the individuals, so that those species which most nearly resemble one another, are brought together into distinct assemblages. The groups thus resulting are called *genera*; and a genus is consequently an assemblage of species, just as a species is an assemblage of individuals.

Thus the ox, the American bison, and the buffalo of Europe, are all so many distinct species, which yet resemble one another so closely as to lead zoologists to associate them along with some other species nearly allied to them into a genus by themselves; the goat and the ibex, with some others, will form a second genus, while the lama will unite with the vicuña to form another, and by proceeding in this way we can distribute all the known species of animals under a certain number of genera.

11. Exactly in the same way certain genera are found to resemble one another more closely than they resemble any other genera, and thus higher groups formed of assemblages of genera may be constructed. These groups are called *families*.

Thus we have the genus composed of the ox, bison, &c., uniting with that which contains the goat and ibex, and with certains others to form one family (*Bovidæ*), while the genus containing the lama and vicuña will unite with that formed for the true camels to constitute another (*Camelidæ*).

12. So also families admit of being distributed under a still smaller number of groups called *orders*, and by the continued application of exactly the same principles, the orders are grouped into *classes*, and finally the classes distributed under a small number of groups of the highest generality, constituting the *primary divisions* or *sub-kingdoms*, of the animal kingdom.

The family of *Bovidæ*, for example, agree with the family of *Camelidæ*, and with the family of the deers (*Cervidæ*), of the musk animals (*Moschidæ*), and of the giraffe (*Giraffidæ*), in many common characters, but especially in the possession of a fourfold stomach adapted for rumination. These families are therefore grouped together in a single order named *Ruminantia*, from the peculiar power they all possess of ruminating.*

* The Ruminantia have been differently arranged by different naturalists; the groups here adopted have been selected in consequence of their being the best fitted to illustrate the

So the *Ruminantia* agree with the orders *Pachydermata*, *Carnivora*, *Cetacea*, and various others in numerous common points of structure, but most strikingly in the possession of special glands for the secretion of milk; all these orders are therefore brought together to constitute the class *Mammalia*; while the *Mammalia* form with the classes *Aves*, *Reptilia*, *Amphibia*, and *Pisces*, the sub-kingdom *Vertebrata*; and this sub-kingdom unites with all the other sub-kingdoms to compose the whole animal kingdom.

13. The great steps of subordination then in the animal kingdom arranged in succession, according to their decreasing degrees of comprehensiveness are—

SUB-KINGDOM,
CLASS,
ORDER,
FAMILY,
GENUS,
SPECIES.

It very often happens, however, especially when the groups belonging to any of the above steps are particularly numerous, and present much variation in the degree of difference on which they are founded, that for purposes of exact classification certain intermediate steps will be needed, which will then intervene between some two of those just enumerated. These intercalated steps are generally distinguished by the affix *sub*, as *sub-class*, *sub-order*, *sub-genus*, *sub-species*.*

14. All classificatory groups, as we have already seen, are based upon the mutual resemblances of the objects grouped; but an important question now occurs. Are the same kind of resemblances to be employed in the construction of all such groups, no matter what may be the rank of these in the graduated scale of comprehensive-

particular point under discussion, namely, the subordination of classificatory groups.

* Further intermediate steps are also sometimes employed, such as *Section* and *Tribe*.

ness? Are the same kind of resemblances to be used in the grouping of individuals into a species, of species into a genus, of genera into a family, and so on? We answer, that the resemblances employed in these different cases are not all of the same kind; but to understand how this is, the reader must first have a clear idea of what is meant by—

15. *Subordination of characters.*—It is evident that all the characters presented by a living being are not of equal importance. Some exercise a more marked influence on the entire structure than others, and are causes of many other properties, or, at least, are constantly coexistent with them. Now it is these which are considered the important or predominant characters in contradistinction to those which do not so constantly coexist with numerous other definite properties, and which are therefore considered as subordinate.

Now, in the construction of the more comprehensive groups, the *important* characters of the objects are made the basis of the classification, the subordinate characters being left out of consideration, while such objects as are brought together in the narrower groups, must resemble one another not only in the important characters, but also in the *subordinate* ones.

16. Thus the general plan of formation, such, for instance, as is presented by the composition of the body out of a succession of segments on the one hand, or the absence of all segmentation on the other, affords a character of the highest importance, for we find such variations always associated with marked changes in the whole structure of the animal. In the construction, therefore, of the primary groups of the animal kingdom we employ characters of this class. The general conformation and situation of the centres of the nervous system also afford characters of great importance, and in conjunction with those just mentioned are employed in the formation of the primary groups. Very important characters may also be derived from the respiratory and circulatory systems; but as variations in these systems are not so univer-

sally found associated with important variations of the rest of the organization, the characters derived from them are considered of less importance than those derived from the chief modifications of the nervous system, and can therefore only be employed in the formation of groups of a lower rank; while in the formation of such inferior groups as genera and species, the zoologist employs characters derived from organs of but slight physiological importance, as, for instance, those afforded by the sculpture and colouring of the superficial covering of the body, or by slight modifications of form, and relative size of external organs.

17. (3.) *Arrangement.*—But our groups may be all constructed in exact accordance with the principles now laid down, and may, moreover, have their respective ranks properly assigned to them in the scale of subordination, and yet each may occupy a position in the general scheme of the classification, which would place it in connection with other groups to which it had little or no alliance, and the classification would thus so far fail in one of its most important ends. The objects, therefore, must not only be grouped, and the groups properly subordinated, but these groups must also be *arranged* in accordance with their *natural affinities*, so that those which possess the closest affinities shall, if possible, be brought nearest together, and those whose affinities are most remote, shall be most widely separated. In this way the entire scheme of the classification will form a definite series, the degree of proximity of whose members will be the true measure of their actual resemblances.

18. A careful investigation of the affinities of animals has led to one very important result, which the zoologist should never lose sight of, namely, the impossibility of representing all these affinities by an arrangement of animals in a simple linear series. Each group possesses affinities not merely in two directions, one connecting it with a group above it, and the other with a group below it, like a link in a chain; but its affinities branch out, as it were, in various directions, connecting it with several

different groups; and thus, instead of admitting of representation in an uninterrupted linear series, the natural affinities of animals can only be fully expressed by several series with connecting branches. Were we fully acquainted with all the properties of every animal, the natural affinities of the animal kingdom might be thus expressed by a ramified figure, which would be one of great complexity; but as we are still ignorant of innumerable properties, it is generally most convenient in our tabular schemes to adopt the simple linear mode of representation, contenting ourselves with expressing the affinities as fully as this mode will allow.

19. Diagnosis.—When we have once formed a group, the next step is to define it. For this purpose we have recourse to what naturalists call the *Character* or *Diagnosis* of the group. This consists in a certain number of properties selected from among the assemblage of those which gave rise to the formation of the group, and enables us to distinguish the particular group to which it applies, from all others included along with it in a more comprehensive one. Thus the class of birds (*Aves*) may be distinguished from all other classes in the more comprehensive group, Vertebrata, by the following diagnosis:—

"Warm-blooded oviparous animals, destitute of organs of lactation; heart with four cavities; circulation complete; respiration by lungs; skin covered with feathers."

20. Nomenclature.—But though our groups be all correctly formed, defined, and placed in their proper positions in their respective ranks, it is not sufficient to indicate them by asserting that one group is a species, another a genus, another a family, and so on. Our groups would still want stability, they would be perpetually changing and eluding our intellectual grasp, were it not that we possess some additional means of binding together their component parts, and fixing them under our examination. The necessary aid is here afforded by *nomenclature*, which imposes a distinguishing

name on each group, and thus unites with the diagnosis in holding together its fickle elements, so that assemblages become, as it were individualized, and rendered definite and permanent subjects of contemplation.

21. Perhaps the greatest of all the services rendered by Linnæus to natural history was his admirable invention of a *binary nomenclature*. By this device every specific group is called by two names, one indicating the genus under which the species is immediately included, the other being some distinctive appellation by which it is separated from every other species of the same genus.

All those species, for instance, such as the American bison and the European buffalo, which resemble the ox so closely as to be associated with it into a single genus, have received the common or *generic* name of *Bos*; all those such as the wolf and the jackal which are united into the same genus with the dog have been named *Canis*; those which belong to the same genus with the cat, such as the tiger and the lion are called *Felis*, and so on; but besides the generic name which is thus common to all the species of the same genus, each of the species is distinguished by a name peculiar to itself, which is called the *specific* name, and is placed immediately after that of the genus. Thus the common ox is called *Bos taurus*; the bison, *Bos Americanus*; the buffalo, *Bos bubalus*; so also the dog is *Canis familiaris*; the wolf, *Canis lupus*: the cat, *Felis catus*; the tiger, *Felis tigris*; the lion, *Felis leo*.

22. Natural and Artificial Classification.—The reader has been already informed that the true test of the value of a group in every classification which is intended to become an instrument for the investigation of nature, is that the group shall be such as will admit of numerous important general propositions being asserted in common of all the objects contained in it, and we have seen that such groups must therefore be founded on resemblances which are both numerous and important. Groups of this kind are called *natural*, and every classification which is founded on them and constructed in

obedience to the laws, which we have been endeavouring to explain, is called a natural classification. But instead of assuming as the basis of the classification numerous and important resemblances, it is possible to classify objects according to their resemblance in one or two characters of minor importance, selected for some purpose of simple convenience, but without any reference to the essential resemblances or natural affinities of the object grouped. A classification founded upon this principle is said to be *artificial*.

23. The difference between a natural and an artificial classification may be familiarly illustrated by referring to the arrangement of the names of books in a catalogue. If the alphabetical position of the letters in the names be made the basis of the arrangement, a very convenient method for reference will be the result; but as the alphabetical order of the letters can have no connection with the nature of the subjects on which the books treat, or with any other important properties, the classification founded upon it will be eminently artificial. On the other hand, the *subjects* treated of will afford numerous important properties which may be made, as in a *catalogue raisonné*, the basis of a different kind of classification which will then correspond to what in natural history would be called a natural classification.

It is obvious that if any system of classification were purely artificial, objects of the most dissimilar kind would be brought together, while such as closely resemble one another would be widely separated. If all birds, for instance, were classed according to the colour of their plumage, so that all those with black plumage would be placed in one group, those with white in another, those with red in a third, and so on; we would have, it is true, a collection of definite groups, but each group would be composed of objects, most of which would differ in every important property from one another. Now it must be quite apparent that such a classification as this could serve no scientific purpose whatever, it would not contain a single group which

would admit of any important general assertion, and such groups as could go no farther than to enable us to think together of all birds which had feathers of the same colour, would, so far from promoting scientific investigation, be utterly subversive of it.

24. When artificial systems, however, are employed in natural history, the artificial element is never carried to the extent indicated in the examples just adduced: in such artificial systems as can be of the slightest use in natural history, the subordinate groups, at least, must be natural; and in the most celebrated artificial system in existence, that invented by Linnæus, for the classification of the vegetable kingdom, it should be carefully borne in mind that the narrower groups, the genera and species, are based upon such resemblances as must render them truly natural, while the artificial method is alone applied in the formation of the more comprehensive groups, the classes and orders, under which the subordinate ones are included.*

LESSON II.

PRIMARY GROUPS AND CLASSES OF THE ANIMAL KINGDOM.

"Praise ye the Lord. Beasts, and all cattle; creeping things, and flying fowl."

1. At a time when our knowledge of the structure of organic beings was but little advanced, naturalists were not in possession of a sufficient number of facts to enable them to apply the principles of natural classification, in such a way as to lead to results of much importance; and as most of the earlier systems merely aimed at affording an easy mode of determining the

* For further information on the general principles of classification, the student may consult Whewell's 'Philosophy of the Inductive Sciences,' Mill's 'System of Logic,' and Comte's 'Philosophie Positive.'

position of any particular object in the classification, and thence arriving at its name, the artificial method which was well adapted for this purpose was in general use.

New views, however, of the real end of classification began gradually to develop themselves; naturalists at length became convinced that the old systems were inadequate for the purposes of scientific investigation, and every day rendered it more apparent that as an instrument for such investigation, a classification could only be perfect when it constituted a concise but comprehensive statement of the actual structure and relations of the objects classified. Accordingly the efforts of the systematist were henceforward mainly directed to the perfecting of the natural method; and as scientific discovery and philosophic classification mutually aided one another's progress, classification has now been brought to a state of perfection, which in an earlier stage of our knowledge of nature was impossible.

2. The laws of a natural or philosophic classification being now properly understood, we shall proceed in the next place to examine the leading groups into which, in accordance with these laws, zoologists have divided the whole animal kingdom.

THE FIVE SUB-KINGDOMS OF ANIMALS.—A comprehensive survey of the animal kingdom shows that there are five great modifications of form, in accordance with one or other of which every animal is constructed, and which may be represented respectively by a Dog, a Lobster, a Snail, a Sea-anemone, and a Trumpet-animalcule.

Now these modifications are made the basis of the primary groups of the animal kingdom, which is thus divided into five great sub-kingdoms, named as follows: I. VERTEBRATA. II. ANNULOSA. III. MOLLUSCA. IV. RADIATA. V. PROTOSOA.

I. VERTEBRATA.—The vertebrata (fig. 3) possess an internal skeleton, of which the essential part is specially framed for the protection of the great nervous centre, and consists of a series of successive segments called

vertebræ. By the union of the vertebræ a continuous more or less bony case is formed, which, under the name

Skeleton of Perch.

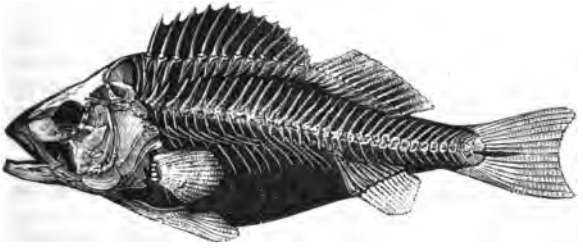


Fig. 3.

of skull and vertebral column, lies upon the dorsal aspect of the body, and encloses the nervous centre known as the brain and spinal cord. The skeleton constitutes the solid framework of the body, and affords points of attachment for the different muscles, and levers for locomotion. In almost all the vertebrata, moreover, the apparatus for circulation is well developed, and the heart presents at least two distinct chambers.* The limbs are never more than four, and there are usually distinct organs for sight, hearing, smell, and taste, placed upon the head.

A Man or a Dog will afford familiar examples of the vertebrata; but a Bird, a Lizard, a Frog, and a Fish, will present equally good illustrations.

II. Annulosa.—In the Annulosa (fig. 4) the body presents, as in the vertebrata, a series of successive segments, which, however, are here not confined to the parts in immediate connection with the nervous centre. A greater or smaller number of these segments usually carry external appendages or limbs. The nervous centre which is usually in the form of a ganglionic

* The curious and anomalous genus *amphioxus* is an exceptional form of vertebrata.

chain, lies in the greater portion of its extent upon that part of the animal which is turned downwards, and when a skeleton exists, this skeleton has no special relation to the nervous centre, and is placed on the outer surface of the body. The alimentary canal is distinct from the general cavity of the body.

PLAN OF LOBSTER.

Fig. 4.

A Beetle, a Lobster, a Nereis or other sea-worm, afford examples of the annulosa.

III. MOLLUSCA.—In the Mollusca (fig 5) the body no longer presents successive segments, and there are never articulated limbs. The nervous centre which never forms a ganglionic chain, lies chiefly on the inferior aspect, as in the Annulosa. There is no proper internal skeleton. The alimentary canal is distinct from the general cavity of the body. The body is soft, enveloped in a flexible and contractile skin, and often protected by one or more solid plates or shells.

PLAN OF CUTTLE-FISH.

Fig. 5.

Familiar examples are afforded by the Cuttle-fish, the Snail, and the Oyster.

IV. RADIATA.*—In the Radiata (fig. 6) the alimen-

* The Radiata, as here defined, coincide exactly with the group named CŒLENTERATA, by Frey and Leuckart. The term Cœlenterata is certainly quite expressive of the essential character of the group, but there is hardly on this account sufficient reason for replacing by it the original term Radiata, which I therefore here retain, though in a sense very much

tary canal is no longer distinct from the general cavity of the body, but either absolutely coincides with it, or opens freely into it. The body is not composed of successive segments, but in by far the greater number of instances has the parts arranged in a radiate manner round a common centre or axis, and a distinct nervous system is mostly absent.

MEDUSA.

Fig. 6.

Examples are afforded by a Sea-anemone, a Medusa, and a Hydra.

V. PROTOZOA.—In the Protozoa (fig. 7) we have animals of the simplest possible organization. They present no distinctly-defined system of organs, and the body may be compared to a simple cell or vesicle with a more or less differentiated wall filled with soft or semi-fluid contents, in the midst of which is almost always a more solid body called a nucleus. They are almost all of microscopic minuteness.

Examples are afforded by the Stentor or Trumpet-animalcule, and by the Amœba or Proteus.

Such are the five primary groups, or sub-kingdoms, into which the whole animal kingdom admits of being divided. But each of these groups is itself composed of animals, which, though resembling one another in their

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restricted when compared with the Cuvierian employment of this word.

great leading characters, possess nevertheless most important differences, and thus afford occasion for still

AMŒBA.

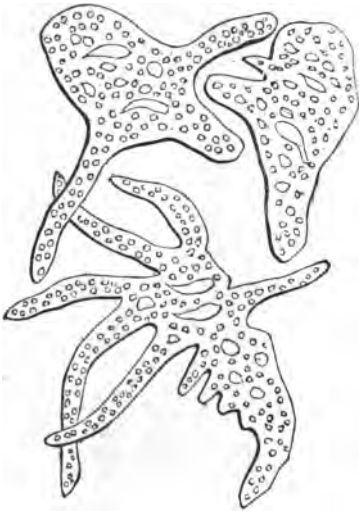


Fig. 7.

further division. Accordingly the sub-kingdoms are themselves subdivided into secondary groups or classes; and to the formation and characters of these groups we shall now attend.

3. DIVISION OF THE SUB-KINGDOMS INTO CLASSES.—When the VERTEBRATA are compared with one another, it will be at once seen that some are furnished with special organs for the supply of milk to the newly-born young which are brought forth alive; others are destitute of such organs, and the young are produced from eggs; some breathe the atmospheric air by means of lungs, in others the respiration is carried on by means of gills, adapted for the separation of air from the sur-

rounding water in which the animal is destined to live. In some the circulation is effected by a completely double heart, in others the heart is single or only imperfectly double. Some have warm blood, others are cold-blooded. Some have their entire organization fitting them to live in the water, others can only live on the land, while some are constructed for flight. These differences afford characters of great importance, and indicate the existence of five distinct classes of vertebrate animals. We have thus the Vertebrata divided into the following classes:—

1. *Mammalia.*
2. *Aves.*
3. *Reptilia.*
4. *Amphibia.*
5. *Pisces.*

4. (1.) *Mammalia* (milk-giving animals) (fig. 8) bring forth their young alive, and nourish them during a certain time with milk secreted by special glands. They have warm blood, a heart with four cavities, a complete circulation, and respiration by lungs. The skin is almost always covered with hair. Examples—Man, Dog, Ox.

PLAN OF A MAMMAL.

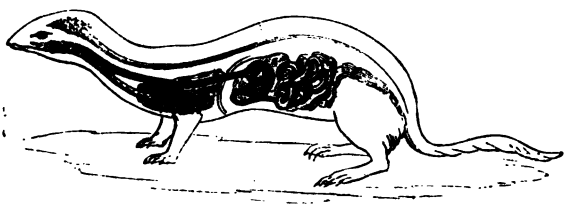


Fig. 8.

(2.) *Aves* (Birds) (fig. 9) are oviparous, and destitute of glands for the secretion of milk. They have warm blood; a heart with four cavities, a complete circulation, and respiration by lungs. The skin is covered with feathers. Examples—Eagle, Rook, Gull.

(3.) *Reptilia* (Reptiles) (fig. 10) are oviparous, and

destitute of organs of lactation. They have cold blood,

LAMMERGIER.

Fig. 9.

a heart mostly with but three cavities, incomplete circulation, and respiration by lungs alone. The skin is

LIZARD.

Fig. 10.

mostly covered with scales or bony plates. Examples—Tortoise, Crocodile, Viper.

(4.) *Amphibia* (Frog-like animals) (fig. 11) are oviparous, and destitute of organs of lactation. They have cold blood, a heart with three cavities, and incomplete circulation. They are provided with lungs, and in their young state have also gills. The skin is mostly naked. Examples—Frog, Newt, Axolotl.

(5.) *Pisces* (Fishes) (fig. 3) are oviparous, and destitute of organs of lactation. They have cold blood, a heart with two cavities, and complete circulation. They breathe exclusively by gills, and are never furnished with true lungs. The skin is mostly covered with scales or plates. Examples—Perch, Cod, Ray, Shark.

5. The ANNULOSA comprise a group of animals which, though all constructed on the common plan already described, present nevertheless such very various modifications of this plan that it has been found convenient to group these modifications under two subordinate plans immediately derivable from the more general one.

TREE-FROG.

Fig. 11.

In one of these the segments of the body are furnished with articulated appendages, which, in a certain number of the anterior segments are so modified as to become fitted for the functions of sensation and manducation. In almost every case there is a distinct heart and arterial vessel, which always communicates with the general cavity of the body; and the centre of the nervous system consists of a chain of ganglia. To this group the name of *Articulata* has been given.

The second of the two great plans discoverable among the annulose animals comprises such as are deprived of true articulated appendages, and have a blood-vascular system, wherever this has been demonstrated, invariably closed, so as to present no communication with the general cavity of the body.* The name of *Annuloida* (Huxley) has been given to this group.

* The system of closed vessels here referred to are considered by Huxley as not representing a true blood-vascular system (see his lectures on General Natural History in 'Medical Times,' where the subject is forcibly argued). Until, however, further evidence in favour of Professor Huxley's view is obtained, I prefer adhering to the more generally-adopted opinion, though still regarding the question as an open one.

Now under these two sections are included all the classes of the Annulosa.

Under the *Articulata* we have the four following classes:—

1. *Insecta.*
2. *Myriapoda.*
3. *Arachnida.*
4. *Crustacea.*

(1.) *Insecta* (Insects) (fig. 12) have the body divided into three distinct regions (head, thorax, and abdomen).

HUMBLE-BEE.

Fig. 12.

The head is furnished with antennæ, the thorax carries six feet, and the abdomen is destitute of articulated appendages. The respiration is aërial. There are almost always wings which are borne on the thorax. Examples—Cockchafer, Bee, Butterfly, Locust.

CENTIPEDE.

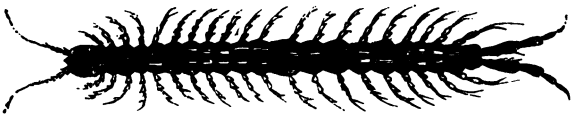


Fig. 13.

(2.) *Myriapoda* (Myriapods) have a very much elongated body, divided into a great number of

rings, and there is no distinction between thorax and abdomen. The head is furnished with antennæ, and the feet are very numerous, one pair at least being borne upon each ring. The respiration is aërial. They are never furnished with wings. Examples— Centipede, Julus.

(3.) *Arachnida* (Spiders) (fig. 14) have the head and thorax mostly united into a single region. There are no antennæ. The legs are eight in number. The abdomen is destitute of articulated appendages. The respiration is aërial. There are never wings. Examples —Spider, Scorpion.

MYGALE.

Fig. 14.

(4.) *Crustacea* (Crabs) (fig. 15) are furnished with antennæ. They have articulated appendages on head, thorax, and abdomen. The respiration is aquatic. They are never provided with wings. Examples—Crab, Lobster.

Under the *Annuloida* the three following classes are embraced:—

1. *Annelida.* 2. *Scolecida.** 3. *Echinodermata..*†

CRAYFISH.

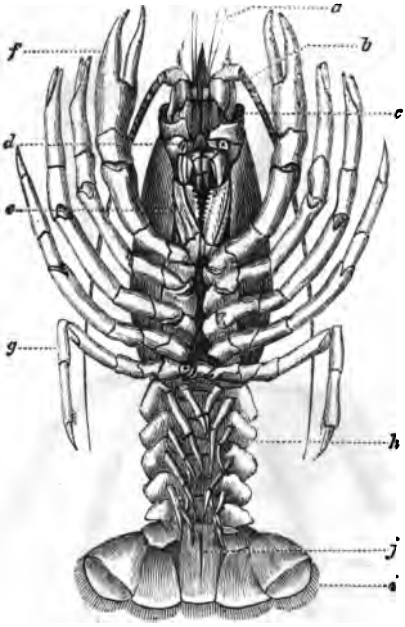


Fig. 15.

The *Annelida* (fig. 16) have the consecutive rings of which the body is composed, for the most part very distinct, a complete alimentary canal, and the nervous system in the form of a ganglionic chain running along the under side of the body, and perforated in front by the alimentary canal. There is almost in every instance a peculiar system of completely closed tubes, usually regarded as a blood vascular system.

Examples of the *Annelida* are presented by the Nereis, the Serpula, and the Earthworm.

* So named by Busk.

† The position here assigned to the *Echinodermata*, and first proposed by Huxley (see his lectures on General Natural History in 'Medical Times'), appears to be the only one it is possible to give to this group in a natural classification, unless we assume it as constituting a distinct *primary* group of the animal kingdom, a view taken by J. Victor Carus (Thierische Morphologie, p. 467, and Icones Zootomicæ). With the exception of a radiate arrangement of their organs, which, after all, can be shown to be more apparent than real, the Echinodermata do not possess a single character by which they can fall into the Radiata of Cuvier; and the typical members of that group, to which, in the classification here given, the term Radiata is confined, are constructed on a plan altogether different.

The *Scolecida* (figs. 17 and 18) have the annulation of

NEREIS.

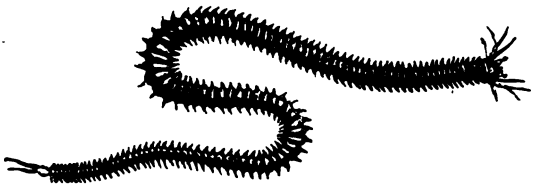


Fig. 16.

the body, obscure, or even entirely obsolete. The ner-

WHEEL-ANIMALCULE.

DIPLOSTOMUM.

Fig. 17.

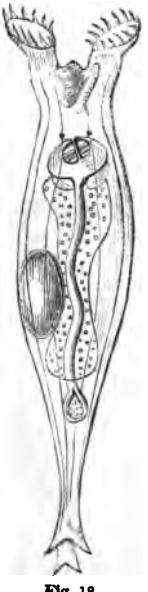


Fig. 18.

vous system does not present a true ganglionic chain. The alimentary canal is usually incomplete, and in some orders totally absent. A peculiar system of tubes, ("water-vascular system") by which water is admitted from without to the interior of the body, has in most instances been demonstrated.

The *Scolecida* are mostly parasitical worms living in the interior of other animals. Examples of these parasitic forms are afforded by the Ascaris, the Fluke, and the Diplostomum, while the Planaria and the Wheel-animalcule afford examples of the non-parasitic forms.

The *Echinodermata* (fig. 19) are distinguished from the other Annuloida by the greater or less development in

STARFISH.

Fig. 19.

the skin of calcareous plates, which frequently constitute a complete case enclosing the softer parts of the animal;

but especially by a remarkable system of water-tubes which are connected with a series of protrusible suckers or *ambulacra* employed in locomotion. There is also a system of completely-closed tubes resembling that of the Annelida, and like it usually regarded as a blood-vascular system. The nervous system consists of fine cords lying in the lines of the ambulacra, and connected together by a ring which surrounds the œsophagus.

The Starfish, the Sea-Urchin and the Holothuria afford characteristic examples of the Echinodermata.

The numerous animals included under the sub-kingdom of the MOLLUSCA, also present differences of great importance which give occasion to the division of this sub-kingdom into a certain number of classes. When, however, the classes of the mollusca are compared with one another, it will be seen that while they all possess the essential characters of molluscan organization, they are yet constructed upon two different plans. In one of these the nervous centre and the region of the body which is more directly related to this centre have a comparatively large development, the centre of the nervous system consisting essentially of three pairs of ganglia. The circulatory system is also well developed. In the other plan the nervous centre and the region of the body more directly related to it remain comparatively undeveloped, the nervous centre consisting merely of a single ganglion. The circulatory system also presents a very low grade of development, in some cases there being no trace of either heart or blood-vessels.

These differences give rise to the formation of two sections intermediate between the sub-kingdom and its classes, and the mollusca constructed in accordance with the former type of organization are included in the section of the *Mollusca Proper*, while those which are referable to the latter type constitute the section of the *Molluscoida*.

6. The *Mollusca Proper* admit of being divided into three classes, namely, 1. *Cephalopoda*. 2. *Cephalophora*. 3. *Acephala*.

(1.) *Cephalopoda* (Cuttle-fishes) (fig. 20) are furnished with a very distinct head, which bears a number of arms disposed around the mouth, employed more or less in locomotion and prehension. The nervous system and organs of sense acquire a higher degree of development than in any of the other invertebrate animals. In the interior of the head is a rudimentary cartilaginous skeleton. Some of the Cephalopoda are provided with a peculiarly-formed univalve shell, and most of them contain in the substance of the integument a calcareous or horny support. Examples — Cuttle-fish, Argonaut, Nautilus.

Octopus.

Fig. 20.

(2.) *Cephalophora* (Univalves) (fig. 21) have also, in almost every instance, a distinct head, which however is here destitute of the arms which characterize the Cephalopoda. Special organs of sense are almost always present and placed in the head. A bivalve shell is never present; but the animal is in most cases protected by a shell composed of a single piece, which passes through all gradations of form, from that of a simple flat plate, to a

spirally-wound tube. The organs of motion are generally well developed, and consist either of a fleshy muscular disc, placed horizontally on the under surface of the animal (*Gasteropoda*), or of a keel-shaped organ for swimming, occupying a similar situation, and placed vertically (*Heteropoda*), or of two fin-like appendages

FRESH-WATER SNAIL.

Fig. 21.

placed symmetrically one on each side of the body (*Pteropoda*). Examples — Snail, Whelk, Carinaria, Clio.

(3.) *Acephala* (Bivalves) (fig. 22) are all destitute of a distinct head; the body is enveloped in a mantle composed of two folds of the integument, and the whole is enclosed in a bivalve shell. Examples—Tellina, Oyster.

TELLINA.

Fig. 22.

7. The *Molluscoida* include two* classes, namely, 1. The *Tunicata*. 2. The *Polyzoa*.

* Recent investigations into the structure of the *Brachiopoda* would seem to justify the association of these mollusca

(1.) *Tunicata* (fig. 23) are wholly enclosed, and permanently fixed in a membranous sac withtwoopenings, one for the admission of water to the gills and of food to the mouth, the other for the rejection of excrementitious matter. The respiratory system consists of a large sac placed before the mouth, and containing a branchial apparatus, whose construction varies in different orders. There is, in almost every instance, a distinct rhythmically contracting heart, which, however, reverses its action periodically, a succession of contractions from behind forwards being followed by another series of contractions from before backwards. Examples—Ascidia, Perophora.

PEROPHORA.

Fig. 23.

(2.) *Polyzoa* (fig. 24) are like the Ascidia, enclosed in an external sac, which, however, has but one opening, and through this the animal has the power of projecting and retracting the anterior portion of its body. The respiratory apparatus is composed of a crown of ciliated tentacula placed round the mouth. There is no trace of a heart. The Polyzoa are all composite animals, developing themselves in plant-like clusters by a process of budding from an original individual. The external sac is almost always strengthened by the secretion of

---

with the *Molluscoida* rather than with the *Mollusca proper*. (See Huxley in article *Mollusca*, in 'English Cyclopædia.') The question, however, must be still regarded as an open one, and while it may seem premature to decide on the molluscoidal relations of these animals, it would be just as rash to affirm the contrary. If the Brachiopoda be viewed as Molluscoida, they will constitute a third group of this section.

PLUMATELLA—*a*, natural size; *b*, magnified.

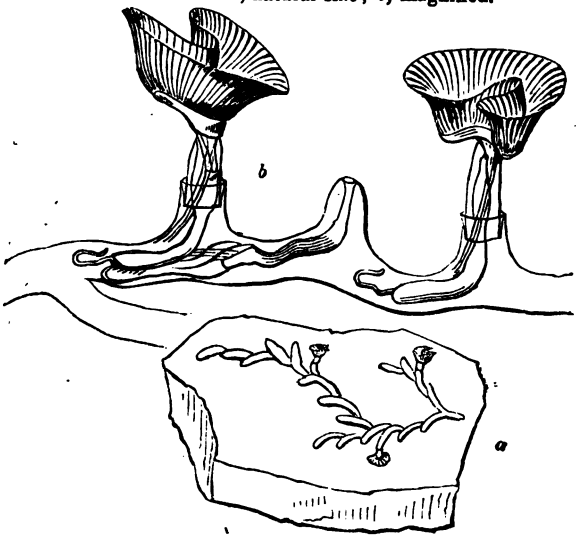


Fig. 24.

SEA-ANEMONES.

Fig. 25.

calcareous or other solid matter.—Examples Flustra, Plumatella.

The *Radiata* are divided into two classes.

1. *Actinozoa.* 2. *Hydrozoa.*

The *Actinozoa* (fig. 25) embrace such of the Radiata as have the alimentary canal furnished with distinct walls, and suspended in the general cavity of the body, with which, however, it freely communicates.

The Actineæ, or Sea-Anemones and the Coral animals may be taken as examples of the Actinozoa.

The Hydrozoa (figs. 26 and 27) are those Radiata which have no distinct walls to the alimentary canal, and in which the digestive function therefore devolves exclusively on the general cavity of the body.

PLAN OF HYDRA.

Fig. 26.

As examples of the Hydrozoa may be mentioned the fresh-water Hydra, the Laomedea, and the Medusa.

The PROTOZOA are divided into three classes, namely,—

1. *Infusoria.*
2. *Rhizopoda.*
3. *Gregarinæ.*

The *Infusoria* (fig. 28) are Protozoa mostly provided with a mouth, and in which locomotion is effected by vibratile cilia, or flagelliform appendages, or long, stiff, bristle-like processes.

They occur in pools, and in infusions of organic substances, and in the sea. Examples are seen in the Stentor or Trumpet-animalcule, and in the Vorticella.

The *Rhizopoda* (fig. 7) are Protozoa always destitute of mouth, and in which locomotion is effected by

fleshy processes, (" pseudopods,") which the animal has the power of thrusting out from the surface of its soft, plastic, body.

The Rhizopoda occur, like the Infusoria, in infusion of organic matter, and in fresh-water pools and the sea. Examples—Amœba, Nonionina.

The *Gregarinæ* (fig. 29) are Protozoa which, like the Rhizopoda, are invariably destitute of mouth, and are never furnished with cilia, pseudopods, or any other arrangement for locomotion, beyond what may be afforded by simple undulations of their walls.

LAOMEDEA.

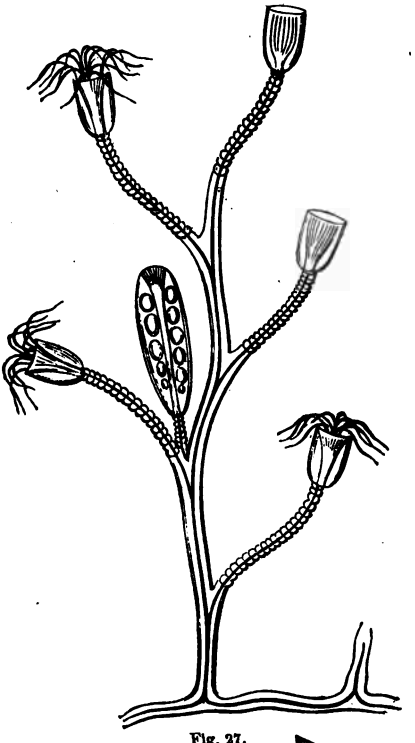


Fig. 27.

Our knowledge of the Gregarinæ as a distinct group of animals, is the result of recent microscopical research. They constitute a small group of parasitical organisms, and are all found in the intestinal canal of invertebrate animals. Example—Gregarina. Such are the

sub-kingdoms, or primary divisions, of the animal kingdom, and the subordinate groups into which each of these sub-kingdoms is immediately divisible.

GROUP OF INFUSORIA.

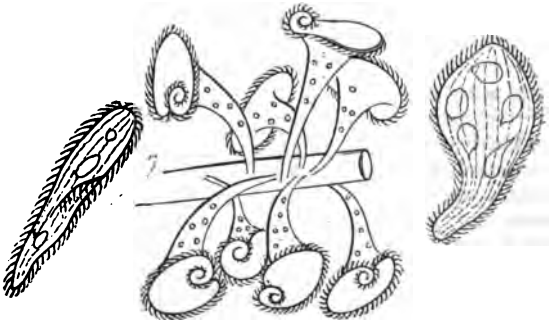


Fig. 28.

The limits within which it is necessary to confine the present article render it impossible to pursue in this place the subdivision further than we have now done, and we must refer the reader to the various systematic treatises, where he will find the classification of the particular groups carried out in detail. The groups,

GREGARINA.

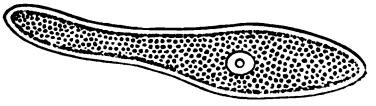


Fig. 29.

however, here enumerated and defined will, we trust, enable the student to form a correct idea of all the leading variations of form presented by animals; and to understand the principles in accordance with which the groups of a natural classification must be constructed.

GEORGE J. ALLMAN.

Arts and Manufactures.

CALICO PRINTING.

BY GRACE CALVERT.

"Now Israel loved Joseph more than all his children, and he made him a coat of many colours."

1. This interesting and prosperous branch of manufacturing industry has sprung up nearly within the present century, and it is principally within the last twenty-five years that it has risen to its wonderful magnitude and importance, and that the various styles of calico printing have been carried out to their present state of comparative perfection. The art of calico printing has become of late years such an important branch of manufacture in the cities of Glasgow and Manchester, that at least twenty millions of pieces of calico are printed yearly in the latter city alone, and its immediate neighbourhood.

Limited as I am for space, I shall attempt to give but an outline of the various processes by which calico-printers give to their prints those beautiful and varied effects of pattern and colour which commerce requires. It is necessary here to remark that I shall confine myself to cotton fabrics, as the processes for printing woollen or silk goods, or a mixture of these with cotton, are generally different from those followed for calico prints.

2. Before a piece of calico can be printed or dyed, it is essential that it should undergo several processes. The first process has for its object the removal of the fibrous down, or nap, from the surface of the calico. To effect this the pieces are singed, by passing them rapidly over red-hot iron rollers, or through a flame produced by combustion—a mixture of hydrogen gas and oxide of carbon, or by that of the heavy carburetted hydrogen,

commonly called coal gas.* In the latter case the flame passes through the fabric, owing to the gas being not only forced out from the aperture by pressure, but from its being also drawn through the fabric by a rapid draught established above the jets of gas by means of a powerful fan.†

3. *Bleaching.*—The calico, being ready for bleaching, is submitted to a continued process for removing impurities and bleaching.

4. The following table will give an insight into the nature of the impurities to be removed, and the agents by which this object is effected :—

Impurities in Cotton.	Soluble in
Gelatine Soda and potash Starch and sugar Albumin	Water.
Perspiration of the hands Gluten	Lime water.
Fatty matters Lime and soap Resins Green and yellow colouring matters	Caustic soda.
Resins and gum resins Iron and terreous substances Colouring matters	Acids.

A piece of calico intended to be used for printing must be more thoroughly deprived of its impurities than when it is simply intended to be sold in the white; for if any heterogeneous substances remain attached to the fibres, they fix colours in the various processes of dyeing or printing, and thus give rise to stains. The loss which a piece of calico experiences in its bleaching, by the

* Invented by Mr. Hall, 1818.

† Invented by Berthollet, 1797. First applied in England by Messrs. Tennants of Manchester.

removal of the above impurities, varies from 25 to 30 per cent. of its weight.

5. *Drying.* — The fibre of the calico having been thoroughly washed in various washing-machines, to deprive it of foreign matters, is next placed in a "hydro-extractor," which consists of a cylinder in which the calico is placed, and to which a rapid rotatory motion is given. By the centrifugal force thus excited the water is driven out of the calico. The cloth to be dried being placed in the cylinder, it is set in motion and soon acquires a rotatory velocity equal to 900 or 1000 revolutions per minute. The water is thereby driven from the calico through perforations, and finds its way out of the machine. The calico being nearly dry when taken out, is then ready to be stretched and completely deprived of its moisture. To attain this purpose it is made to pass through a series of wooden rollers covered with felt, and then over a set of zinc ones, heated by steam, made to circulate through them. This mode of drying is exceedingly simple, rapid, and economic. The moisture of the piece being transformed into vapour, by the heat of the steam inside the hollow zinc cylinders, is removed rapidly from the room by means of a fan placed over the apparatus.

6. One of the most simple styles of calico printing is the one employed to obtain plain indigo blue, and which is technically called "blue dipping." No doubt this mode of dyeing is also one of the most ancient, as it was practised centuries ago in India. This circumstance is probably due to the indigofera plant, which yields indigo with great facility, growing abundantly in that country. To obtain this valuable colouring matter it is simply necessary to place the mown indigo plant in large vats, where it is allowed to enter into fermentation, when the white soluble indigo thus liberated gradually becomes green, and then blue; and as in this state indigo is insoluble, it precipitates.

7. To facilitate the deposit, lime is added in the vat, and on the water being run off, the indigo is gathered,

made into small cakes and dried in the sun. To dye with this indigo, as well as with that which is imported into this country from the West Indies and South America, it is ground into a fine powder, and 30 lbs. of it are added to about 900 gallons of water, in which have been previously dissolved 70 lbs. of green copperas or sulphate of protoxide of iron, and to these are added 106 lbs. of slaked lime. The following chemical reaction will explain how the blue indigo, losing a part of its oxygen, becomes white, and soluble in the excess of lime employed.

Blue indigo .	White indigo Oxygen	Indigotate of lime.
2 pts. sulphate of protoxide of iron . .	2 Protoxide of iron 2 Sulphuric acid	Peroxide of iron.
3 pts. of lime.	1 pt. lime 2 pts. lime	2 pts. sulphate of lime.

8. After the lapse of a few hours, the dye-vat being ready for dyeing, a piece of calico is hooked on a wooden frame and well stretched out. A man at each end taking hold of the frame, dips it into a vat containing lime, and then in the above-mentioned one of indigo for five minutes. It is then taken out and exposed to the air five minutes. The object of this last operation is to oxidize the white indigo, and therefore the calico is first observed to become green and then blue, in consequence of the oxygen of the atmosphere fixing itself on the white indigo, and rendering it gradually insoluble indigo which is fixed on the cloth.

These dippings in the cold indigo vat and exposures to the atmosphere are repeated until the piece has acquired the necessary shade of blue. The piece should now be passed into a weak solution of sulphuric acid, or "sours," and then well washed and dried. A piece of calico so dried being rough and uneven, could not be sold at the present day, consequently it is necessary to submit it to a series of processes whose object is to give to the

fabric such an appearance as will please the eye of the buyer, and obtain a better price in the market. All these finishing processes have one common end, namely, to fill up the interstices which exist between the fibres, and thus give to the calico a more substantial and glossy appearance. This is effected by filling the calico with boiled starch, farina, or wheat flour which has been fermented and washed: to these substances are often added large quantities of sulphates of lime or baryta. To give a close appearance to the piece, it is passed through heated rollers, with pressure; and according to the heat and pressure applied, so is the degree of lustre acquired by the fabric.

9. To produce on a piece of blue indigo white figures or drawings, several methods are employed by the calico printer, but I shall describe here only two of them.

Reserves.—The calico printer has often to produce a style of print which is much worn, not only in our rural districts, but also in many distant parts of the globe, namely, "indigo blue" having white spots or designs. These kinds of prints are produced by a very simple process, which is indeed described by the technical term applied to specify it, namely "reserved blues." It consists in applying such substances as will preserve the white calico from being dyed in all those parts where the reserve has been applied. Those substances which act as acids, thereby precipitating the indigo from its lime solution before it has penetrated into the fibres, act as "reserves." There is, however, another class of substances which is preferred to acids. It comprehends those which, at the same time that they act as acids, also furnish oxygen to the white soluble indigo, and by thus oxidizing it, render it blue and incapable of fixing itself in the fibres of the cotton. The salts of copper possess this property in a very high degree, and are chiefly used for this style of printing. The following is an outline of one of the modes adopted:—a piece of calico is made to pass over the roller of a printing machine, and the following reserve is deposited

or printed on all those parts of the piece which are to remain white:—

2·500 acetate of copper.
1·890 sulphate of copper.
·300 nitrate of copper.
·300 sulphuric acid.
5·600 pipe-clay.
1·890 British gum.

The reserve thus deposited is dried by passing piece over heated plates, or cylinders, in which steam circulates. The piece of cotton is then hooked on a frame, and dipped in the above-described indigo-vat. None of the reserved parts fix the colouring matter, or indigotine, whilst the other parts of the calico take up the colour. When the required shade of blue is attained, the piece is washed, soured in weak vitriol, well washed again, and dried. By these operations the indigo is completely fixed, the reserve removed, and a blue print, with white designs, produced.

10. This style of printing leads me to explain a modification of it which enables the calico printer to obtain a very nice print in great demand in Greece and Asia. It is a blue indigo print, with orange designs instead of the white ones just described. To produce this print it is simply necessary to prepare a reserve having a different composition from the one above described, as follows:—

18 litres water.
20 kils. nitrate of lead.
8·500 pyro-lignite of lead.
20·0 sulphate of copper.
13·6 sulphate of lead.
13·20 pipe-clay.
36·350 gum-water containing 850 grains per litre.

The piece having been dipped in the indigo-vat, slightly washed, soured, and again slightly washed, is passed through a boiling alkaline bath of bichromate of potash, when the chromic acid combines with the oxide of lead contained in the reserve, in the state of sulphate of lead, and thus produces an orange-yellow of chromate of lead.

11. *Discharges.*—There is another mode besides the one above described of producing white spots or designs on indigo blues. It consists in placing a blue-dyed piece of calico on a table which is covered with a thick blanket, and then a workman applies a discharge to the piece of cotton. This can be effected either by means of a printing machine, or by a block of sycamore, holly, or pear-tree woods, about nine inches long and six inches broad, on which is carved the design in relief as in ordinary woodcuts. At other times the design on the block is produced by the insertion of thin slips of copper, the interstices being filled with felted cloth, which imbibes the discharge or colour, which the block-printer takes from flat pieces of woollen fabric, on which has been spread a thin layer of the matter to be printed. In this case the discharge is composed of chromate of lead, thickened with flour or starch, and then applied to the piece of indigo-blue calico wherever white designs are to be produced. The piece of calico, after it is printed and left to dry, is passed through a bath composed of hydrochloric acid of sp. gr. 1·050, and containing 1 oz. of oxalic acid per gallon. A chemical reaction ensues between the chromic acid of the chromate of lead and the oxalic and hydrochloric acids, producing chlorine gas, which destroys the blue indigotine in every part of the print where the discharge has been applied. Thus white designs are obtained.

12. There are several other substances and modes known for discharging colours, but they all consist in removing some of the substances combined with, and colouring the fibre. To give another example, I will mention that white designs are obtained on black grounds by applying, either with the printing machine or blocks, the following discharge:—

10 litres	water.
1·875 kils.	oxalic acid.
1·250	tartaric acid.
·312	sulphuric acid.
5·000	calcined farina.

The print is dried to fix the discharge, and then dipped into water, when the citric, oxalic, or tartaric acids combine with the oxide of iron, which, with tannin matter, formed the black fixed in the fabric, and thus dissolving, liberates the tannin matter, and leaves a white design in all those parts where the discharge has been applied.

GRACE CALVERT.

Biography.

SIR RICHARD ARKWRIGHT.

BY GEORGE L. CRAIK.

1. SIR RICHARD ARKWRIGHT may be styled the father of the cotton manufacture, which is the first manufacture of the first manufacturing country in the world. The present population of the British islands may be taken in round numbers at thirty millions: if it have not yet attained quite that amount, it is at least on the point of reaching it, and certainly, at the lowest calculation, the number of persons entirely dependent upon, and supported by this one manufacture, is full a million. But, speaking still in round numbers, we may say, that the population of England is as nearly as may be, three times that of Ireland, and that of Ireland, just about twice that of Scotland; in other words, we may divide the thirty millions into nine parts, of which Scotland will have one, Ireland two, and England six; this expression at least of the relative numbers of people in the three countries may be assumed to be nearly constant, and is very convenient for recollection. Applied to our assumed sum total of thirty millions, it would give us somewhat above twenty-three millions for the population of Great Britain, which is the only part of the empire in which the cotton manufacture can be said to be established. Probably, therefore, this manufacture

now forms the support of not much, if any, less than a twentieth of the entire population of England and Scotland. It is distributed principally over Lancashire, Cheshire, Derbyshire, the West Riding of Yorkshire, the counties of Nottingham and Lincoln, and those of Lanark and Renfrew in Scotland. Throughout these districts this single manufacture employs and sustains probably a fourth of the population; in some of them a much higher proportion.

2. Yet this vast source of our national wealth and strength, far surpassing any other branch of commerce or manufactures, and only to be matched in productiveness and importance by the total agricultural industry of the country, which is more properly to be compared with the whole mass of that which is manufacturing and commercial, is the creation of only the last seventy or eighty years, or of the space of little more than an ordinary life-time. Persons who still survive may be said to have witnessed its beginning or infancy. Even in 1784, which is only seventy-four years ago, the annual importation of cotton amounted to hardly more than ten millions of pounds; it may be now stated at between five and six hundred millions.

3. Arkwright had already been for some time in the field; but as yet only fighting, almost as in a field of battle. His victory and his harvest of wealth and prosperity, for himself, for many others, and we may say for his country generally, were still to come. He was a Lancashire man, a native of the town of Preston: he was born there on the 23rd of December, 1732. It does not appear exactly what his father was; but he was at any rate only a poor labourer or artizan: and Richard was the youngest of thirteen children. The boy certainly received very little education; it has been doubted, indeed, if he ever was at school; yet, as he appears to have been able to read and write, he probably was. The business to which he was brought up was that of a barber; possibly that may have been the occupation which his father followed. Nothing farther is told or

known of him till he had nearly reached the age of thirty. At this time he was established as a barber in the town of Bolton, in Lancashire, then commonly distinguished as Bolton-le-Moor, that is, Bolton near or by the side of the moor. About the year 1760, it is related, he left off shaving, and took to travelling about the country and collecting hair, which he cleaned and dressed, and then sold to the wig-makers. Here was a clear manifestation of the progressive spirit of the man; he was now no longer a mere workman, but had elevated himself into a dealer and speculator.

4. The law of all unskilled labour is, that no man can ever make more by it than another, and that in ordinary circumstances, nothing can ever be made of it beyond a bare subsistence; if any description of such labour were to be paid at a higher than the ordinary rate, additional labourers would be attracted to it as certainly as water flows into a hollow, and would soon restore the level. Nothing but an absolute want or scarcity of human hands, such as could only occur in a very young community, or an imperfectly-peopled country, could prevent such a result. Shaving may not perhaps deserve to be regarded as an absolutely unskilled handicraft; superior dexterity might here be able to operate with at least more expedition, if not otherwise in any higher style; but that would come to little or nothing if there were only, as commonly would be the case, a certain limited number of beards to be shaved. Arkwright, even supposing him to have been able to ply his razor faster than another, would probably not have made anything by offering to perform his function for a halfpenny while others charged a penny. That would not have answered unless he could have more than doubled the number of his customers, as well as despatched twice as many in a given time as any one else.

5. For one who was, as we may suppose to have been the case with him, much more a man of head than of hand, his new employment offered a far more promising sphere of exertion. Even in the mere selling of an

article, there is no limit to the extent to which profits may be increased by activity and enterprise; every extension of the field of supply is a gain, so long as the price realized can only be kept up to something, no matter how little, above the cost of production, and the charges of management (including the interest upon capital); and these are quantities, the proportion of which, or their pressure upon each transaction, almost always diminishes somewhat, often diminishes greatly, with the increase of transactions. But whoever sells must also either produce or buy; and here (with corresponding risks, no doubt, and chances of loss and discomfiture to the imprudent and incompetent) are yet more ample and various opportunities of gain for skill, judgment, and sharpness. And Arkwright did not satisfy himself with merely collecting the article in which he dealt, he also dressed the hair, and prepared it for sale. He was thus in some sort a manufacturer, as well as a buyer and seller. It is said that he had discovered, or in some way or other acquired the knowledge of, an improved method of dyeing the hair, which was not generally known; and that, at any rate, whether by the advantage which he derived from the possession of this secret, or merely by taking more pains, he was enabled to offer his customers, the wig-makers, a better article than they could commonly elsewhere procure.

6. It would not appear, however, that whatever reputation he may have got, he made much money in the new line upon which he had thus set out. We hear of him as being still, some time after this, in great poverty. No doubt he must have sometimes been a loser as well as a gainer, and that both in time and in money, by his deviations from the ordinary course. That is a liability incidental to every kind of speculation and adventure. It is in general only after several attempts and several failures, that even the most fortunate ingenuity and sagacity are at last rewarded with success; and Arkwright was a man whom hardly any number of failures would have prevented from trying again. His whole

career shows this; and his incapacity of feeling himself to be beaten is the finest feature in his character.

7. Whatever may have been his reason, he seems to have, after a few years, got tired of the hair-selling business, as he had previously done of his original occupation. He could not indeed expect anything very brilliant in the way of pecuniary result from the one more than from the other. Ambition is natural to him who is conscious of superior talents; and Arkwright must have felt that he was not yet even on the road that led to his proper position. It has been suggested that his acquaintance with the chemical secret which he had found of use in preparing his supplies for the wig-makers may have first awakened his taste for discoveries in the arts. However that may be, the next thing we hear of him is, that he was busying himself about the perpetual motion. And the glimpses we catch of him in this the first stage of his history, in which his existence is disclosed to us, present the usual characteristics of a person of a projecting and inventive turn of mind, who has not yet found the object that is to fix him. There are the sanguine avidity with which one new scheme is taken up after another, the appearance of unsettledness thence arising, the indifference with which everything belonging only to the actual present, is regarded in comparison with the promises of the imaginary future. Many such ingenious persons, and some even largely gifted with originality of mind, never get beyond this state of mere expectation and vision-seeing; but Arkwright, in addition to his inventive talent, was eminently endowed with other qualities, both intellectual and moral, of a less showy nature, by which that is often not accompanied, and yet without which it is fully as apt to ruin its possessor as to make his fortune.

8. He soon drops the perpetual motion. Before the end of the year 1767 he had begun to direct his attention to a far more important problem.

Various attempts had been made for some time before this to apply machinery to the spinning of cotton.

So early as in the year 1733, a machine for that purpose is said to have been contrived by a Mr. Wyatt of Lichfield, and operations to have been actually begun by him in factories which he built both at Birmingham and Northampton. The undertaking, however, seems to have failed; it certainly was not persevered in; and no model of Mr. Wyatt's apparatus has been preserved, nor even any description of it. As little is known of another machine said to have been produced by a Mr. Lawrence Earnshaw, of Mottram, in Cheshire, about twenty years later, which spun and reeled the cotton at one operation: it is told that the inventor merely showed it to his neighbours, and then destroyed it, not being able to satisfy himself that its effect might not be to diminish the employment of human labour, and so to deprive the poor of bread. Even if such a consequence were unfortunately to be the inevitable result, it is pretty evident that it would have to be submitted to, unless we could find some way of actually putting an end to the power of ingenuity and invention: it would be in vain for society to attempt to put down all the clever people simply that the stupid might have the better chance. But in truth machinery is never the working man's enemy or competitor, but in all cases only his helpmate; instead of less, it leaves him always more to do, and also more to receive for what he does. Lastly, in this very year, 1767, a carpenter of Blackburn, in Lancashire, named Hargrave, or Hargraves, had invented the machine popularly called the spinning-jenny, which spun twenty or thirty threads at once; but he had been obliged to fly from Lancashire, to escape the vengeance of the mob. He took refuge in the town of Nottingham, but he was obliged to abandon his speculation; and he died some years afterwards in poverty and obscurity.

9. At this time such was the demand for spun cotton, that there were 50,000 persons employed in Lancashire, mostly, if not all, females, each plying her spinning-wheel from morning to night; and yet the required quantity was not to be obtained. The common practice

had been for the weavers to get what they used spun by their wives and daughters for them; but now, we are told by an historian of the cotton manufacture, "those weavers whose families could not furnish the necessary supply of weft had their spinning done by their neighbours, and were obliged to pay more for the spinning than the price allowed by their masters; and, even with this disadvantage, very few could procure weft enough to keep themselves constantly employed. It was no uncommon thing for a weaver to walk three or four miles in a morning, and call on five or six spinners, before he could collect weft to serve him for the remainder of the day; and, when he wished to weave a piece in a shorter time than usual, a new ribbon or gown was necessary to quicken the exertions of the spinner."

10. It is evident that unless some remedy could be found out for this state of things the progress of the manufacture must have been arrested. One of its essential departments could not be carried farther at the charge for wages which the finished article would bear. The case was the same as that of the book-trade would be if the cost of producing paper were from any cause to be so much augmented that people, who would otherwise buy books, pould, to a great extent, do without them rather than way the price at which alone they could on that account be sold. Yet what was called cotton cloth at this date, was only in part made of cotton. It was only his *weft*, as we have just seen, that the weaver had to provide for himself. This forming the threads driven cross-wise by the shuttle, was what it was his business to put into the web; hence the name; it was the interwoven portion of the tissue. The warp, as the longitudinal threads are called, was, so far as the weaver was concerned, rather a part of the loom; it was like the soil into which he was to put the seed. And it was always of yarn; neither by hand with the common distaff and spindle, or wheel, as it was called, nor by any machine that had yet been tried or devised, either Wyatt's, or Earnshaw's, or Hargrave's,

had thread been spun strong enough to be used for the warp. The notion of the possibility of spinning such cotton thread had probably never entered the head of anybody.

11. The preceding spinning machines had apparently been merely contrivances for working together, and under the action of one wheel what were substantially only a number of distaffs and spindles. They were but combinations or collections of distaffs. Their principle of mechanism was simply the substitution of a single turning and twisting power for the feet and hands of so many spinners. That was the utmost that they ever aimed at accomplishing, whether they may have actually effected so much imperfectly or completely, in but an indifferent or in a tolerably satisfactory way. It was reserved for Arkwright to invent quite a new kind of spinning, and a kind which was to prove infinitely superior to the old one in the quality of the product as well as in the facility of the operation.

12. His own account was, that his invention was first suggested to him by seeing a bar of red-hot iron elongated, by being passed between rollers. But this was a simple and obvious process, merely an instance of the common effect of pressure, in comparison with his plan for the drawing out of cotton-wool into thread. The principal, or at least the mechanical arrangement which he employed for this purpose, was quite new. It consisted in making the cotton, after it had been passed through one pair of rollers, *be taken up by a second pair revolving several times faster than the first.* The effect of this obviously would be to elongate the original thick layer, or rope, as it might be called, exactly in proportion to the difference of the two velocities, or, in other words, with a proper contrivance for giving it, at the same time, the requisite twist, to convert it into a thread of any degree of fineness that might be desired, and that the nature of the material would admit of. It is certainly one of the happiest and most beautiful conceptions in the whole range of mechanics.

13. When Arkwright hit upon this brilliant thought —as great a discovery almost as if he had found an Aladdin's lamp—he was nearly or absolutely penniless. It is ascertained that before the end of the year 1767, he had gone with his scheme to a Mr. Atherton of Liverpool, and tried to persuade him to help him—but perhaps he did not explain himself so fully as he might have done; it has been said that the wretched state of Arkwright's attire determined that gentleman to have nothing to do with him—at any rate he declined to risk his money; although we are told, when Arkwright was some short time after enabled to make a beginning in the erection of his machinery, by assistance from another quarter, Mr. Atherton sent some of his workmen to help him. His first successful application was to a Preston tradesman of the name of Smalley—a liquor-merchant and painter he is said to have been—who was possessed of a little money, and who also had an influential acquaintanceship with the master of the Free Grammar School of Preston. It was in the parlour of the house belonging to this functionary that Arkwright proceeded, early in the year 1768, to construct his first working machine, after a model which he had brought with him when he came to the town. It is asserted that he was at this time so ill off as to be almost in rags; he was a burgess of Preston by birth or apprenticeship, and an election contest took place shortly after his arrival, when it is said his party were ashamed to bring him up to give his vote till a subscription was made to procure him a decent suit of clothes. From so low a point had the man to raise himself who was to found one of the most colossal of modern fortunes! It is another lesson in the great truth, and invaluable practical belief, that if only we are resolute in doing our best, no mere opposition of external circumstances, short of what is absolutely insuperable, is ever a ground for despair.

14. His appearance in the subscription suit of clothes, when he presented himself to vote at the election, was almost the last of Arkwright that his native town saw

for the present. Immediately after this he left Preston. The recent fate of Hargrave, he tells us himself, had alarmed him; he had come to think that neither his spinning-machinery nor himself would be safe among the working people of Lancashire. It is probable also that his patron, the liquor-merchant or painter, shared in these apprehensions; and Smalley's little stock of money, besides, seems now to have been exhausted.

15. Taking his model with him, and accompanied by Smalley, and also by a John Kay, originally a watch-maker, whom he had brought with him to Preston, he now betook himself to the town of Nottingham. This was still in the year 1768. Here he addressed himself to the Messrs. Wright, the bankers, and they at first went into his project; but they soon declined to go on with their advances. He now applied to Mr. Jedediah Strutt, of the firm of Need and Strutt, stocking-weavers; and Mr. Strutt, who was a person of great intelligence, and well versed in mechanical science, at once perceived the value of the invention, and he and his partner forthwith entered into partnership with its author. We may suppose that Smalley was now paid off; as for Kay, of whom we shall have more to say presently, he is stated to have been guilty of conduct for which it became necessary to turn him off. A patent having been taken out in Arkwright's name, the first spinning-mill upon the new principle was at last set up at Nottingham, the moving force employed being that of horses, in 1769. Let the year be remembered and held in honour as that of the birth of a great power of peaceful industry, as well as of Napoleon and Wellington.

16. A second mill was erected by Arkwright and his partners in 1771 at Cromford, in the parish of Wirksworth in Derbyshire, in which water was used as the moving power; and in 1775 he took out a second patent for additions which he had made to his original apparatus. The value of the invention was now completely established. It had become, indeed, an indis-

pensable part of the national industry. It had already revolutionised the cotton manufacture, not only by putting an end to the difficulty in obtaining a supply of thread, but by producing it of so superior a quality to any before known, that it could now be employed for the warp as well as for the weft, and cloth could for the first time be fabricated wholly of cotton.

17. It is not to be wondered at that others should envy the good fortune of Arkwright and his partners, and long to share in it; but the improvement which he had introduced into the business of spinning was of so decisive a character that nothing could be done in attempting to compete with him without making use of his own inventions. This was accordingly what soon began to be done. Arkwright bore for some time with the invasion of his patent rights in various quarters; but at last, in 1781, he determined to proceed with actions for damages against nine different parties. The first case, which was, in fact, to determine them all, came on for trial in the Court of King's Bench, at Westminster, in July of that year. It was brought against a Colonel Mordaunt. The only ground that this defendant took, was the insufficiency, as he contended, of Arkwright's specification. In other words, he alleged that the description of his invention which the patentee had lodged when he claimed his patent, and in return for which it was in truth to be held that he had received his temporary right of monopoly, was not such as really to communicate his secret, or to enable others to construct the machinery. It is not improbable that there may have been some truth in this. Arkwright may have thought it quite enough to give such a description as would suffice in the meantime to distinguish his mode of spinning from any other. This is not what the law requires—and properly requires; for, on the one hand, so vague a statement might be made to cover much more than the patentee had actually invented, and on the other, it might enable him in many cases to enjoy his monopoly without dis-

turbance for the term included in the patent, and after all to retain his secret, or, in other words, to defraud the public of the price in consideration of which that protection had been granted. The latter consequence could not well have been apprehended in the case of such an invention as Arkwright's, the principle of which must have become known to all the world, as in fact it did, as soon as the machinery was set up and put in motion; and he may therefore have held that he was justified in speaking about it with some reserve while it was in course of erection. On this ground, however, of the insufficiency of the specification, a verdict was now given for the defendant Mordaunt; and he, and all the other spinners who had adopted the new machinery (for the other eight actions were dropped) were left, with all such as chose to follow their example, to persist in their invasion of Arkwright's patent with impunity. Yet their plea that the invention was insufficiently described might almost be said to be refuted by the fact that they had been able to steal it. If it was insufficiently described in the specification, it was at any rate made plain enough in the actual machine, which it was plainly impossible to prevent from being seen by many eyes.

Arkwright took no farther steps to protect himself for some time. At length he brought a second action against one of the invading parties, which was tried in the Court of Common Pleas in February, 1785; and, having now produced several practical machine-makers who gave evidence in favour of the sufficiency of the specification, he this time obtained a verdict establishing the validity of the patent.

18. Not a word, it is to be observed, had hitherto been said in court about any other objection to the patent except the insufficiency of the specification only. That the invention was not new, or was not the patentee's own, had never been whispered or hinted at. The defendants admitted, or at least did not deny, that they were pirates, that they had stolen and were trading upon an invention

which was not their own; they only contended that their piracy was not legally punishable. It is asserted, indeed, that some of the persons against whom the first actions were brought in 1781 had intended, if the cases had been tried, to maintain that Arkwright himself had stolen the invention; it has been averred that two witnesses who were ready to swear this, one of them having been brought over from Ireland for the purpose, were actually in court during the trial of the action against Mordaunt, but, at any rate, it is certain that neither of them was produced either on that occasion or four years afterwards, when the next trial took place.

19. The two witnesses, however, were still extant. And, having now failed in their other plea, the parties interested in the destruction of the patent, at last, as if in desperation, determined to venture upon bringing them forward. With this view a writ of *scire facias* for the repeal of the patent was taken out, and the case came on for trial in the Court of King's Bench in June, 1785. The insufficiency of the specification was again alleged; but in addition, it was now charged that the author of the invention was not Arkwright, but a poor reed-maker named Highs or Hayes, who in 1767, while living in the town of Leigh, had applied to Kay, the watchmaker, already mentioned, who was then resident in the same place, and was his neighbour and acquaintance, to make him a model of a spinning-apparatus upon the principle of the double pair of rollers. The secret, it was affirmed, was communicated to Arkwright by Kay when they became acquainted shortly afterwards at Warrington. This story was supported by the evidence both of Kay and of Highs (it was the latter who had been brought over from Ireland in 1781), and also by that of Kay's wife, who, however, only professed to recollect her husband making models of some kind or other first for Highs and then for Arkwright.

20. It was obviously impossible that evidence such as this could be met at the moment by any direct confutation. It could only be resisted on the ground of its in-

herent improbability. It related to transactions that had taken place seventeen or eighteen years before. For all that long time the witnesses had been silent, notwithstanding that the subject of Arkwright's patent had been so much before the public, and they had all been mostly resident in the very district, where it had excited the greatest attention, and been canvassed with the keenest interest, so as to be universally familiar to man, woman, and child. The evidence of Kay, besides, was of the most tainted character; for he had by his own showing been a party to the fraud and wrong which he now thus tardily came forward to expose. Nevertheless, after a trial which lasted from nine o'clock in the morning till half-past twelve at night, a verdict was returned declaring the patent to be bad. Arkwright, in the following November, applied for a new trial, representing that he was now prepared with affidavits contradicting many things in the evidence of Kay and the other witnesses; but the Court refused to grant the motion; it was held that, even if the story which Kay and Highs told should be given up, the verdict ought to stand, and the patent to be invalidated, on the ground of the insufficiency of the specification.

21. After this Arkwright made no more efforts in the Courts of Law, spent no more of his time, money, and strength in the pursuit of justice under difficulties. His friends never doubted that the story brought forward at the last trial was a fiction from beginning to end. He wisely determined to be satisfied with this conviction of those to whom he was best known. And, like a brave man as he showed himself through his whole career, he resolved to try whether, as he had taken the start of others in inventive ingenuity, he could not also set his rivals and opponents at defiance without the protection of his patent, and only by the exertion of his activity and energy in free and equal competition. The course that he thus took was crowned with the deserved success; but that success was not lightly achieved. He and his partners had expended more than

twelve thousand pounds before the speculation in which they had engaged begun to pay. And even to the end of his life Arkwright's attention was almost incessantly given to the superintendence of his various factories. He allowed himself no repose; the work in which his heart was, that was his relaxation. The new branch of industry and of national wealth which he had created became, as it were, his world. And, as he had in a manner made it, so it in return made another man of him, not only in his worldly fortunes and position, but to some extent in mind and facutly. New powers seemed to be developed in him by the new demands made upon him. "The originality and comprehension of Sir Richard Arkwright's mind," says one of his biographers, "were perhaps marked by nothing more strongly than the judgment with which, although new to business, he conducted the great concerns his discoveries gave rise to, and the systematic order and arrangement which he introduced into every department of his extensive works. His plans of management, which must have been entirely his own, since no establishment of similar kind then existed, were universally adopted by others; and, after long experience, they have not yet in any material point been altered or improved."

Arkwright received the honour of knighthood on occasion of going up with an address to the king as High Sheriff of Derby in 1786. Although originally a man of great personal strength, he had been all his life a sufferer from asthma; and he was carried off by a complication of this and other disorders in August. 1792, when he had not yet completed his sixtieth year.

GEORGE L. CRAIK.

Arts and Manufactures.

THE FLAX PLANT.

BY JAMES MACADAM, JUN.

LESSON I.

GROWTH.

"And Solomon had horses brought out of Egypt and linen yarn: the king's merchants received the linen yarn at a price."

1. NEXT to cotton, the vegetable most largely employed in substance, in textile manufactures, is the fibre of the flax plant. Its employment in the fabrication of clothing apparently dates from a very remote antiquity. We find frequent references to it in the Old Testament, the earliest being in the book of Genesis, where it is recorded that, during Joseph's administration of Egypt, Pharaoh arrayed himself in vestures of fine linen. At that period, and for a long time subsequently, flax was grown very extensively in the East, where it is indigenous, and its manufacture was the leading branch of textile industry among the Egyptians. On the walls of certain tombs in Upper Egypt may be seen, to the present day, paintings representing the processes of culture and manufacture; and it would appear that not only was linen the chief, if not the sole article of clothing, in that country, but the Sacred Writings inform us that a considerable export of yarn and flaxen fabrics took place to Israel and Tyre; and according to Herodotus, a like trade was, at a later period, carried on with Greece.

2. The most striking illustration of the extent to which linen was used by the Egyptians is found in the fact that, without an exception, all the mummy-wrappings are composed of flax. This, which had been long disputed, was ascertained beyond doubt, through the use of the microscope. As seen through that instrument the

fibres of cotton appear in the form of flattened cylinders twisted somewhat like a corkscrew, and without any joints; whereas flax fibres are found to be transparent tubes, straight and cylindrical, and jointed like the sugar-cane. These distinctive characters of cotton and flax are presented, no matter how they may have been treated in the processes of manufacture, and the microscope is thus an unerring test. Among the mummy-cloths are some fabrics of extreme fineness, seldom rivalled at the present day, notwithstanding the great facilities for manufacturing flax which the adoption of machinery has afforded. And what makes this still more curious is, that the flax now grown in Egypt is so coarse that it could not be made into a fabric one-third as fine as those which, after a lapse of three thousand years, are to be found in catacombs by the Nile.

3. Originally confined to the East, the flax plant was probably carried across the Mediterranean into Europe by the Phœnician merchants, and the Greek colonists of Egypt and Syria. No other vegetable fibre being then employed by the European nations for clothing, the culture of this plant rapidly spread over all the continent, and its manufacture became an integral part of the domestic routine. The songs and tales of Europe abound with references to this, and the term "spinster" derives its origin from the spinning of flax having been the constant indoor occupation of unmarried women. There does not appear to be any trace of its use in Britain until the Saxon invasion; after that the chronicles and rude illustrations of our ancestors frequently notice it.

It would appear that the flax plant, when acclimated in Europe, found a climate and soil more favourable to the maturing of a fibre suited to the general range of manufacture, for while its growth extended so greatly westwards, it gradually declined in the east. At the present day few Asiatic countries grow flax; and where, as in the peninsula of Hindoostan, it is cultivated, no use is made of the fibre, the seed only being the planter's

object. In Egypt a certain quantity of fibre is yet produced, but of a very indifferent quality as compared with European flax, and it is chiefly consumed in Scotland, to make bagging and other very coarse fabrics.

4. While the plant is to be found, in greater or less quantities, throughout the entire of this continent, the chief sources of supply are embraced within the 48th and 60th parallels of latitude, and between 10° east longitude and 30° west. This, in fact, is the flax zone, and embraces nearly all the countries which furnish the fibre of commerce—Western Russia, Prussia, North Germany, Belgium, Holland, the north of France, and Ireland. Moisture being of great importance to the plant, it is farther to be remarked that the extent of production, in each of these countries, is generally in proportion to the proximity of their provinces to the coast of the sea, from which westerly winds supply the proper degree of humidity. Thus, if we draw a curved line from Paris, through Leipsic, Warsaw, and Minski, to St. Petersburg, we enclose that littoral region which supplies the great mass of flax for European manufactures. There are also some outlying districts which, though beyond the limits before given as the flax zone, are yet capable of producing a certain quantity, from their position on the ocean; as, for example, the districts bordering on the White Sea, the west coast of Finland, and the entire Atlantic margin of France, Spain, and Portugal. The British Isles, from lying within the zone, and from being so fully exposed to the influence of the ocean, are particularly favourable to flax cultivation.

5. Another point to be borne in mind is, that as the plant delights in alluvial soils, the best qualities of fibre are almost invariably found in the valleys of rivers and in the deltas at their mouths. The Lys in Belgium and France, the Rhine, the Scheldt, and Meuse, in the Low Countries, the Elbe and Oder in the German States, the Vistula, Dwina, and Volga in Russia, are all famed for the flax grown on their banks; the deltas of the Rhine and Scheldt are equally cele-

brated, and in our own islands, the Humber and Ouse, with many of the Irish rivers, run through soils celebrated for their flax.

6. While moisture is an indispensable requisite in the production of a good fibre, extreme rapidity of growth, with great heat, are unfavourable. The short, hot summers of Russia, and of the north of Europe generally, prevent the flax there grown from attaining the same softness, lustre, and fineness which the more equable climate of Belgium, Holland, Northern France, and the British Isles are always found to furnish. It is owing to the extreme dryness of the climate of Egypt, that the flax grown there is, like the Russian, harsh, wiry, and without that peculiar silkiness of feel and glossiness of appearance which indicate the qualities most valuable in manufacture. Consequently we find that, although possessed of great strength, these flaxes, being only suitable for the commoner fabrics, are quoted in the market at prices very much below the others. For example, the average price of Russian flax is from 38*l.* to 55*l.* per ton, and of Egyptian 30*l.* to 45*l.*; while Irish and Dutch bring from 50*l.* to 140*l.*, and the finest Belgian often so high as 200*l.* and upwards. The extremely delicate fibre which is raised in the latter country, with great care, pains, and expense, for the manufacture of lace, will sometimes command almost its weight in gold.

7. The cultivation of the flax plant is a very peculiar branch of husbandry, as it includes not only those processes with which the farmer is acquainted in the treatment of other crops, but also, in order that it may be brought to a marketable state, it must undergo certain operations which belong rather to the department of chemistry than that of agriculture, although practice supplies, with the flax-growing farmer, want of chemical knowledge. On the other hand, if a troublesome crop, it is known to hold out great prizes, in the shape of large profits to those who become adepts in its cultivation. Flax will grow on almost any soil, and

good crops of excellent quality have been obtained on very dissimilar ground—on the artificially enriched sands of Belgium, the alluvial polders of Holland, and the clay-slate of Ireland. Generally, it may be stated that the most suitable soil is sound, deep loam, with clay subsoil well drained. It should follow a grain crop, and be succeeded by grass and clover, the seeds of which are sown at the same time as the flax, and it is considered to be the best nurse for these. As flax is sown in April and pulled in August, in case those seeds have not been sown with it, a crop of late turnips, of rape, or of winter vetches, may be put in when the flax is cleared off the ground.

8. In the cultivation of the plant, nothing is of greater importance than to deepen and thoroughly pulverize the soil, as the smaller fibres of the roots are known to penetrate to a depth equal to one-half the height of the stem above ground, or about two feet. All root-weeds require to be carefully gathered away, the plant being much injured where weeds choke it, and prevent the free circulation of air. On light, friable land one ploughing is enough, but on stiffer soils two are necessary, one after harvest, exposing the ridges to the action of frost, and the other in spring, sometimes before, that seeds of weeds may vegetate to be cleared off with harrowing. Flax is not sown in drills, but broadcast, the land being made into flats of about eight feet wide. After two or three good harrowings the land should be rolled, and finally a short-toothed harrow should scratch this surface before sowing. The seed most approved in Belgium and Holland is Russian, called Riga seed, from the port of shipment. Dutch seed is preferred by some farmers in heavy soils. Seed saved at home from a sowing of foreign is equal to any, but it deteriorates year by year, if not renewed from the parent stock. As much of the foreign sort is mixed with seeds of weeds, the latter should be carefully sifted out. Two and a-half imperial bushels to the statute acre is the proper quantity where fibre is the

object; but if a large yield of seed be preferred, one and a-half to one and three-quarter bushels is enough. In the former case the plants grow tall and straight, like larches in a young plantation; in the latter they are short and branchy, and the fibre is much coarser. Before sowing, the land should be once more rolled, and after the seed has been scattered broadcast, it should be covered with a seed-harrow going twice over it, once up and down, and once anglewise; another rolling finishes the operation, leaving the seed buried about an inch. Where grass and clover seeds are sown with the flax, the sower walks after him who sows the flax-seed. It is found that carrots do very well if sown in drills at the same time as the flax. After the pulling of the latter, they can be hoed and liquid-manured.

9. In many flax-growing countries no manure is employed with the flax-crop, and in the British islands it has been generally found, that when manured the plant grows so rank as to be damaged by laying during heavy rains. In Belgium, rape-dust, mixed with urine, is much in favour on light soils. From chemical analysis of the plant, it has been recommended, where the land is of poor quality, to apply a manure consisting of 30 lbs. muriate of potash, 28 lbs. common salt, 34 lbs. burnt gypsum, 54 lbs. bone-dust, and 56 lbs. sulphate of magnesia (Epsom salt), to the acre. Guano has been tried without any decided results.

10. In case many weeds should appear along with the young plants, they should be carefully pulled. In Belgium, women or children are employed, who, with coarse cloths tied round their knees, creep on all-fours. This injures the plant less than walking on it. They are also careful to work facing the wind, so that the plants, laid flat by the pressure, may be blown straight again. Fig. 1, shows the appearance of the flax plant when fit for weeding. No further care is required during the period of growth; and with the exception of the effects of parching drought, before the plant has well covered and shaded the ground, it is subject to no

diseases. Drought acts not merely in scorching the leaves and stunting the growth, but also frequently brings a small black fly, whose ravages cannot be stopped but by rain. In the latter end of June, flax flowers, and the plant then presents a beautiful appearance. Its slight, graceful stems, clothed with lance-shaped leaves, are crowned with a few delicate bell-shaped flowers, of a light blue colour. These are succeeded by the seed-vessel, which is nearly globular, and contains six or eight seeds. It is not considered proper to allow the seeds to arrive at full maturity before pulling the stems, as in that case the fibre is known to become harsh and dry. When the seed is changing from green to pale brown, the fibre is in the best state, while the sap remaining in the stem is sufficient to ripen the seed. At this period about two-thirds of the stalk will be found to have turned yellow. Flax is not cut like grain, but is pulled up by the roots. The Belgians catch a handful of stalks just under the tops, and pull in this way, so that if the flax be of uneven lengths, the longest is pulled first and the shorter stems afterwards, as it is important to keep each sort separate. There is some care taken to

Fig. 1.

keep the root-ends even, like the bristles in a brush, in order that the fibres, when cleaned out, may also be even, which is a point of some importance in determining the manufacturing value.

LESSON II.

PREPARATION.

"She maketh him linen and selleth it; and delivereth girdles unto the merchant."

1. AFTER the flax has been pulled, it is at the option of the grower to dry the stems and stack them first, or at once to steep them in water, and go on with the other processes. In Russia, and some parts of Belgium, the flax is all dried; in Ireland and Holland it is at once steeped after pulling. When it is dried, the handfuls, as pulled, are set up in a form called the "Courtrai stook," composed of the handfuls set on their root-ends with their tops interlacing, and continued on for 8 or 10 feet long in this manner. In six or eight days it is sufficiently dry to be tied up in sheaves, and put in ricks in the field. These ricks are made as follows:— Two poles are laid parallel on the ground, a foot asunder, with a strong upright pole at each end. The bottom poles are laid north and south, so that the sun shall shine alternately on both sides of the rick. The sheaves are built on the bottom poles, the first row across them, and the succeeding rows at right angles with each other, and they are laid tops and roots alternately, to make the rick level. Seven to eight feet is the height of the rick, which is finished by laying a single row lengthwise, and then another row, but with the tops all the same way, which gives a slope to throw off rain, and the whole is slightly thatched with straw. A properly-built rick stands uninjured for months, and the flax remains in this state until the grower can stack it in his yard, or store it in his barn. The seed is taken off at any time afterwards, and the watering operation

is carried out with the stems in the following May. Flax-stems may be stacked for years, if properly dried, without injury to the fibre.

2. The other mode consists in steeping the flax at once, after pulling, in pits or pools of water. These are made 12 to 18 feet broad, and about 4 feet deep. River or rain water is most suitable. If spring-water is the only kind available, it is let into the pools some weeks before steeping, in order that the sun and air may soften the water. The manner in which the seed-

Fig. 2.

pods are separated from the stems, when flax is steeped in this way, is by means of an implement termed a *rippling-comb*, which consists of a row of iron teeth formed of half-inch square rods of iron, screwed into a block of wood; these rods are 3-16ths of an inch asunder at the bottom, ½ inch at the top, and 18 inches long, with the ends tapering to a point, about three inches from the top. They are set with the angles projecting, and not the flat sides. This implement (fig. 2) is screwed across the centre of a 9-feet plank, resting on two stools

or tressels, and a winnowing sheet is placed under all. The men employed to take off the seed-pods sit at each end of the plank, facing each other, and being supplied with the flax in handfuls, are then made up in sheaves and taken to the pool. In dry weather the seed-pods may be dried in the open air, spread on cloths, and turned occasionally with a wooden shovel. In rainy weather they are spread thinly on lofts, or on the barn-floor; and when nearly dry, are finished by a few hours

Fig. 3.

on a corn-kiln, where the temperature is kept at summer heat, as if too hurriedly dried the seed becomes shrivelled. The seed is afterwards threshed out (see fig. 3), and after winnowing, may be used for feeding, or sold to the oil-mills. The chaff and light seeds are very useful for cattle, stirred along with other food.

3. In placing flax in the pool, it is packed in one layer, somewhat sloped, the root ends undermost, and covered with turf sods or straw, with stones laid on the top to keep the whole under water. A small stream of

water, allowed to run slowly through the pool, is useful in conveying away the scum which rises during fermentation, and the colour of the film is thereby much improved. The fermentation is requisite, in order to decompose the gum which causes the fibres to adhere to each other, and to the stems. If we take a stalk of flax, and examine it closely, we find that the fibres form a coating round the woody centre of the stem, just as the fibrous bark of a tree does round the timber. These fibres are glued together by a sort of gum-resin, and it is impossible to free them from this by mechanical means. The fermentation during the steeping process chemically decomposes the gum, and leaves nothing but the pure fibre and the woody pith of the stem. The length of time required for steeping flax varies according to the state of the temperature; it requires generally from eight to fourteen days. The test employed to ascertain the completion of this process is to take a few stalks out of the pool, to break them about the middle; and if the fermentation has gone far enough, the fibre will readily peel off the entire stem, without breaking or adhering to it. This test is tried every six hours after the eighth day, as it is important not to allow the fermentation to proceed farther than this point, which would greatly weaken the fibre.

4. In taking out of the pool, the sheaves are handed out on the bank by men who stand in the water, and are left to drain, set on their root-ends. They are then untied, and the flax is spread on close sheep pasture ground, being laid very even and thin, and it is turned two or three times until thoroughly dry, by means of a long rod. In six to eight days, if the weather be favourable, or in ten to twelve if dry, the grassing is completed. The test here is when the wood breaks readily and separates from the fibre. It is tied up in small bundles, and may be kept any length of time, stacked. The final process, to bring the fibre to a marketable state, is termed *scutching*, and is either done by hand or in a *scutch-mill*. In Belgium, Russia, and Holland all is

scutched by hand. In Ireland the greater portion is done in the mill. When hand-labour is employed, the stems, placed on a flat stone, are beaten with a wooden mallet, or are bruised under millstones. This is to render the wood more easy of separation from the fibre. An upright board, with a slit in it, receives the handful of bruised stems, which the scutcher holds with one hand, while with the other he strikes them with a blunt and sword-shaped instrument of wood, thus splitting off the bruised wood and leaving the fibre entire. The latter is then scraped with a blunt knife, made up into handfuls, and sold in that state. The scutch-mill consists of a set of grooved metal-rollers to bruise the stems, and a series of wooden blades arranged like the spokes of a wheel around a shaft. The workman holds the bruised stems so that they may be exposed to the action of these blades, and no scraping with knives is afterwards necessary. In Ireland there are upwards of 900 scutch-mills driven by water-power, steam, and wind. The produce of marketable fibre is about 5 cwt. per acre.

5. Of late years several inventions have appeared tending to reduce the retting process to greater certainty and despatch. The chief are Schenck's hot-water steep, Watt's steaming process, and Pownall's hot-water steep, with rolling and washing. All of these are in use, in different parts of Ireland and Great Britain, and the first-named is also employed in France, Belgium, Prussia, and Austria. By Schenck's process, flax is retted in sixty hours, in vats, where the water is heated to 90°. By Watt's method the retting is effected in ten to twelve hours. Pownall's process takes much about the same time as Schenck's, but in addition to the retting, the steeped straw is purified by squeezing it between metal rollers, with a stream of water playing on it. The fibre produced on the first and last of these systems is of fair quality, but that done on Watt's method is not much approved of. In the establishments employing these patented processes flax-straw is purchased from the grower just as pulled and dried.

6. The great seats of consumption for flax fibre in the United Kingdom are Leeds, Dundee, and Belfast, and the supply is derived partly from Ireland and certain localities of Great Britain, but mainly from foreign countries. The total annual consumption in our manufactures is about 150,000 tons, of which about 100,000 are imported, chiefly from Russia, Prussia, Belgium, Holland, France, and Egypt. Besides what is sent from these countries to the British Islands, a very large quantity is consumed in their own linen manufactures; and other states, from which we do not import any flax, use up all that they produce or export to their neighbours. A glance at the estimated extent of annual production in all flax-growing countries will be interesting. Russia grows about 150,000 tons; Austria 65,000; the Zollverein States 70,000; France 60,000; Belgium 25,000; Holland 8,000; Ireland 40,000; Great Britain 5,000; Egypt 3,000; Norway, Sweden, and Denmark 10,000. Adding these together, we find the total to be 439,000 tons; and allowing for the quantities produced in other countries, of less importance as regards this branch of agriculture, we may estimate the entire quantity in the globe at half a million of tons annually, worth about twenty-five millions sterling.

7. Let us now examine how this raw material is converted into woven fabrics, and the various uses to which these are applied.

Until near the close of the last century the manufacture of flax, throughout the world, was strictly domestic. The farmer grew his plot of flax, and brought it to the state of fibre; his wife and daughters spun it into yarn on the cottage wheel, and he and his sons wove this yarn into linen, for household use or for sale. Shortly after the introduction of machinery for the spinning of cotton, it was found that it was equally suitable for spinning flax. Several factories were erected for this purpose in the north of England and on the east coast of Scotland. It was found that

coarse yarns only could be made by machinery, so that the spinning of the finer kinds continued for some time longer to be a source of employment to the peasant women. But about 1825 a process was invented, by means of which much finer yarns were produced than previously could be made by machinery. This invention consisted in causing the fibre to pass through hot water, before being twisted on the spindle, and its effect was to make a much finer and closer yarn than before water was employed. Almost simultaneously various improvements in the *hackling* and preparing processes were introduced, and the trade speedily assumed a magnitude which, under the dry-spinning system only, it could not have hoped to attain. Since that period machine-spinning has rapidly increased in Great Britain and Ireland, and has extended to France, Belgium, Germany, Austria, Russia, Switzerland, Italy, the United States of America, &c.

8. The following figures will convey an idea of the relative importance of each country in the flax-spinning trade. Great Britain and Ireland have above 1,200,000 spindles (of which Ireland counts 580,000); France has 400,000; Belgium 130,000; Prussia 60,000; Austria 45,000; Russia 25,000; Switzerland 12,000; the United States of America 30,000: and adding other countries, the entire number of spindles in the world may be put at 2,000,000, and the number of factory workers at 90,000.

When the flax fibre is received at the factory it is first *hackled*. This process consists in drawing the fibre through combs consisting of a number of rows of steel pins or gills, set very close, and of different sizes according to the kind of yarn for which the fibre is intended. These hackles separate or tear away from the longer fibres a cottony part termed *tow*, while at the same time splitting them into minute filaments. The tow is used for certain coarse descriptions of linens; and the long fibres, from which it has been separated, and which are called *dressed line*, are spun into fine

yarns. In all factories a great proportion of the hackling is done on machines constructed for the purpose, and these are of different kinds, all showing great ingenuity in their adaptation. According to the sort of yarn to be produced, the line is spun at its full length, or is cut into shorter sizes. Before spinning it is spread on leather straps, which revolve and pass the line between smooth steel rollers; and by a certain arrangement of this preparing machine, the fibre is stretched, and pressed, and flattened until it comes out in the form of a broad, soft riband. A second and third process of this nature are sometimes necessary, and then the *sliver*, as it is termed, is put through the *roving machine*, which farther presses, combs, and stretches the fibre, finishing by partially twisting them and winding them on bobbins. The last process is effected in the spinning frame itself, where the yarn is lightly twisted and wound on spools. The yarn is finally reeled and made up into bundles, ready for the manufacturer.

Before it is woven, the yarn is boiled in a ley of soda-ash. It is chiefly woven by hand, but for the coarser fabrics the power-loom is employed. About 5,000 of these are in use in the United Kingdom.

The woven fabric is bleached in large establishments, chiefly by chemical means. One of these, in Ireland, bleaches 260,000 pieces of linen yearly, the charge for bleaching which is about 60,000*l.*

After bleaching, linen is made up in different ways, according to the market for which it is intended. As a general rule, the fabrics intended for the home market are very simply made up, while those for foreign markets, especially for South America, are gaudily ornamented. These ornaments consist of paper, highly coloured, and stamped with patterns, in gold and silver, often showing, also, prettily-coloured drawings of landscapes or human figures. Gold and silver threads, ribands, &c., are also employed for ornamentation. It is calculated that 70,000*l.* are annually paid by the Irish linen-merchants for these decorations, which are chiefly obtained from Paris or London. The linens are

finally packed in bales or in boxes, those intended for South America being put up in packages capable of being carried on the back of mules.

9. The comparative yearly extent to which foreign countries take linens from the United Kingdom is shown as follows:—The United States of America take 50 million yards; the West Indies 28 millions; South America 17 millions; Germany 5 millions; our North American colonies 4½ millions; the Australian colonies 4 millions; Spain and Portugal 3½ millions; the Italian States 3 millions; Turkey 1 million; the East Indies and China 2 millions; Africa half a million. The total export was, in 1840, 89,373,431 yards, and in 1856, 146,410,188 yards. Of yarn our exports were, in 1840, 17,733,575 lbs., and in 1856, 25,118,349lbs. Of threads and small articles, in 1840, to the value of 111,261*l.*, and in 1856, 422,536*l.* The total value of all our exports of flaxen manufactures was, in 1840, 4,128,964*l.*, and in 1856, 6,253,760*l.*

It has been calculated that the entire annual value of the linens, yarns, &c., made in the United Kingdom, both for home use and for exportation, reaches about 18,000,000*l.*

Next to Great Britain and Ireland, the Zollverein States are the most important in the linen manufacture, exporting to the value of about 1,000,000*l.* annually. France exports to about the value of 900,000*l.*, and Belgium 450,000*l.* These are the only countries in the world whose linen exports are of any consequence. but the manufacture for home consumption, in Austria, Russia, Switzerland, Italy, &c., is very considerable. Altogether, it may be estimated that the entire value of the linen manufactured throughout the globe reaches ninety millions of pounds sterling annually.

10. Among the purposes to which flax-fibre is applied, are the following:—Ropes, twines, and cordage, canvas, shirtings, sheetings, damask, table-linen, cambric handkerchiefs, drill-coatings, trouserings, blouse-linen, bedticks, carpet-backing, carpet and stair-covers, oiled-cloths, mosquito netting, &c., &c. Even when reduced

to rags, flaxen fabrics are of great utility, being converted into fine writing-paper, for which they are much more suitable than cotton; and, with the veriest refuse of the fibres, felt for roofing houses and sheathing ships.

11. We have hitherto confined ourselves to that portion of the flax plant which is of the greatest importance—its fibre. But the seed, also, is a very valuable product. From it we obtain the oil which is, with slight exceptions, the only vehicle employed in the arts for mixing colours, and has, consequently, an immense consumption. This oil is obtained from the seed by reducing it to powder, heating it, and pressing it by hydraulic power, so as to squeeze out the oil. The oil is fitted for use in painting, by boiling it with red lead or with litharge, which increases its drying nature. The residue of the crushing or pressing operation consists of the farinaceous portions of the seed, and under the name of oil-cake is very extensively employed in the fattening of live-stock, as it contains a large amount of nutriment in small bulk, and is, therefore, well suited for combination with roots, hay and straw, &c., which have large bulk with little nutriment. Oil-mills are to be found in all parts of the country, but Hull, Newcastle-on-Tyne, Liverpool, Leith, and Belfast are the chief marts of this trade. To supply these mills about 800,000 quarters of flax-seed are annually imported, value 2,000,000*l.*, and the demand for the cake is so great that besides the quantity made from this, about 60,000 tons of foreign cake, value 550,000*l.*, are yearly imported into the United Kingdom. The chief sources of this supply are Germany, Denmark, Belgium, France, and the United States of America. Linseed-oil, besides being employed for mixing paints, is also used, and to some extent, in soap-making. It is also occasionally burnt in lamps.

From the foregoing pages it will be apparent that the cultivation of the flax plant, and the preparation of its products for useful purposes, are among the most important of the various branches of industry prosecuted in the civilized world. JAMES MACADAM, JUN.

Arts and Manufactures.

ARTIFICIAL LIGHTS.

BY GEORGE DODD.

"Thy word is a lamp unto my feet, and a light unto my path."

I. OBTAINING A LIGHT.

1. The light which the Almighty commanded, and which is so bounteously supplied to us, must necessarily be superior in beauty and grandeur to any which man can produce. The sun, the moon, the planets, the stars, the aurora borealis, all shed their lovely rays upon the earth, at due times and in due manner; and among many rude and simple nations, the light so obtained suffices for the limited work of daily life. In more civilized countries, however, and especially in those regions where the winter nights are very long, artificial light is necessary, and various means for obtaining it have been devised. In this, as in all similar cases, the ingenuity of man is applied to the materials which God has provided. The animal world, the vegetable world, the minerals buried in the earth, all yield substances whence light can be obtained; and the various modes of obtaining this light give employment to a very large number of persons, and to the exercise of great ingenuity.

2. We seldom produce light without producing heat at the same time; and hence it happens that whether we wish to light a candle or lamp, or to kindle a fire, and have no heated substances at hand, we employ a method which is equally applicable to the one purpose and the other.

3. It is well known to every one that friction tends to produce heat, and light as a consequence of the heat. When Robinson Crusoe is described as having

produced a light by the rubbing together of two pieces of wood, Defoe merely availed himself of a truth long before known: he simply supposed his hero to have called to mind a fact of which he had often heard and read. The plan adopted by the Bosjesmans or Boschmen will serve to illustrate all the others. Sir James Alexander says: — "I asked a Boschman to show me how he made fire. He went and got two small twigs, and with his assegay (a kind of knife) he squared one twig and made a small hole in it, and gave the other a point; then taking out the bone barb of one of his arrows, he supplied its place in the reed with the pointed piece of stick; and placing the squared stick between his soles, he commenced rubbing the arrow-shaft between his palms, and pressing the pointed twig against the square one, repeating the anxious cry of 'hei! hei!' till he got a black dust from the two sticks; and after a quarter of an hour, smoke and a light." The contrast between rude and civilized life must have been instructively shown at this interview; for Sir James proceeds to say:—"At the conclusion of his hard work, I drew a lucifer-match through sand-paper, produced an instantaneous light, and the Bosjesman was smote with amazement."

4. A more speedy effect, than by mere friction, would be produced if a spark or heated particle could be made to fall upon some kind of tinder or light fibrous substance. The natives of the southern part of America, near Cape Horn, are accustomed to rub a piece of pyrite (a sort of iron-stone) against a piece of flint, and to produce sparks which are caught upon a dry woollen substance. This is a rude example of the *flint-and-steel* apparatus, once so well known in our own country, but now almost superseded by better methods. The flint, being struck sharply and obliquely against the steel, cuts off very minute particles of the metal; these particles, heated to a brilliant whiteness by the suddenness and violence of the blow, are the *sparks* with which we are so familiar; and when these sparks fall upon tinder or singed linen

or calico, they bring it instantly to a red heat. Some years ago, before lucifers and congreves were known, the flint-and-steel apparatus employed a large number of persons to fabricate them; the steels and tinder-boxes were made in immense numbers in the neighbourhood of Wolverhampton; while the flints were shaped at Purfleet, Greenhithe, Northfleet, and other places where flint occurs abundantly in the chalk cliffs. When tinder is kindled to a red heat, but not into a flame, a splint of wood does not readily catch fire from it; and it is for this reason that the splint is tipped with sulphur or brimstone, which ignites at a lower temperature than wood. In Germany the tinder employed is called *amadou*, and is prepared from a sort of spongy fungus which grows on the trunks of trees.

5. The *phosphorus-box* was a great improvement on the flint and steel. Phosphorus is a remarkable substance, which kindles at a low temperature; and chemists very reasonably experimented on this substance, as a means of producing artificial light. But phosphorus is a troublesome and even dangerous substance in the hands of any but careful persons. Another apparatus depended on certain chemical discoveries. If chlorate of potash be mixed with sulphur, the mixture will take fire when it touches sulphuric acid; and this property was brought into action in an ingenious way; the mechanism, however, was liable to get out of order, and was too costly for general use.

6. In all these methods of producing a light, one of two things is observable — either the method is too troublesome, or it is too expensive; and many are both troublesome and expensive. It is no wonder therefore, that the cheap and convenient 'lucifers' and 'congreves' should have come largely into use. The action of rubbing a little splint against a piece of sand-paper seems simple enough; but many experiments had to be made, and large sums of money spent, to find out the best mode of preparing these splints for the purpose.

7. The manufacture of these trifling articles is now carried on in England to an enormous extent. At one large saw-mill in London may frequently be seen six or eight piles of yellow pine, each as large as a six-roomed house, and all intended to be cut up into lucifer-splints. If cheap and inferior bits of wood were employed, they would injure the machines used in cutting them; and the timber merchants, on this account, find it cheaper in the end to employ the very best yellow pine, without knots or rents. The deals are cut, by circular saws revolving with great velocity, into pieces three or four inches long; and these pieces or blocks are cut into lucifer splints by a machine in which there are about fifty sharp knives or cutters, fixed in a row. Five blocks are cut at once; and the action is so inconceivably rapid, that there are 120 movements of the cutters in a minute, and 250 splints severed and shaped at each cut; so that there are 30,000 cut in a minute, or 1,800,000 in an hour. Three of these machines, working 10 hours a day each, would therefore produce 54,000,000 per day; and if we assume that there are 300 working days in a year, the produce would be more 16,000,000,000; and as each splint is long enough for two lucifers, we find that one saw-mill alone can prepare the wood for 32,000,000,000 lucifers in a year. It is difficult to form a clear conception of such large numbers as these; but it will serve to illustrate the subject, if we state that the lucifers cut and shaped *weekly* at this one establishment, if placed end to end, would reach from England to Australia. Four hundred large deal planks are required to produce this weekly quantity. Some lucifer splints are made cylindrical, like wire; they are shaped by being driven through a number of small holes in a steel plate; but there is necessarily a waste of material in this mode of manufacture, however closely the holes may be arranged in the plate.

8. The splints are sold by the timber merchants who cut them, to other persons who tip them with composition, and make boxes to hold them. This trade

is largely carried on in the eastern part of London. The lucifer-makers dry the splints thoroughly, and tie them in compact bundles; each bundle is dipped at both ends into melted sulphur (for the splints are long enough to make two matches each, and are afterwards cut); and when this sulphuring is completed, the splints are tipped with a composition containing phosphorus and several other ingredients. This work is done by children. The boxes are made also by children with great rapidity; and one boy or girl can fill 3,000 or 4,000 boxes in a day.

9. Not only is the quantity of lucifers made in England extremely large, but we also import to a considerable extent from Germany. In the year 1849 there were no less than 50,000 cwts. of lucifers made in Austria alone; these required, besides timber, 325 cwts. of phosphorus, 1,250 cwts. of nitre, and 15,000 cwts. of sulphur. Some of the German timber merchants sell splints to the match-makers at so low a price as about one English farthing for 400 splints.

II. LIGHT FROM SOLID SUBSTANCES.—CANDLES.

10. Nearly every nation in the world makes use of tallow, or some kind of solid fat, as a material whence to obtain artificial light. All such substances consist chiefly of hydrogen and carbon, and are very combustible; but they do not readily take fire unless separated into small melted streamlets. We might hold a light against the side of a candle and melt it until the tallow flows downwards, and yet it would not be kindled into a flame. It is to assist in this separation that a *wick* is provided. The wick, being formed of threads of cotton, has numerous little channels or openings between the threads; the upper part of the tallow is melted into a a kind of oil by the heat of the flame; this oil ascends the little channels between the threads of the wick, and each slender streamlet thus formed will ignite when a light is applied to it. The entire flame of a candle thus consists of many minute flames grouped together, each

belonging to one of the small ascending columns of melted tallow.

11. In some of the country districts the cottagers make rushlights for their own use. The Rev. Gilbert White, in his "Natural History of Selborne," describes the plan adopted in Hampshire and Wiltshire in his day. Rushes were cut in summer or autumn, peeled, dried in the sun, and laid by for winter use. The fat employed was any kind of tallow, skimmings, or fat which the domestic proceedings of the cottage could afford. The rushes were dipped into the melted fat, and each one thus became a rushlight. At the present time, when candles are cheaper than in former days, cottage-made rushlights are less known.

12. The substances which are suitable for being made into candles are numerous, but very unequal in price. Wax is one of the most expensive. In making wax-candles the wicks are allowed to hang freely downwards over a vessel, melted wax is poured over them in sufficient quantity to form the thickness of a candle, and each candle, when cold, is rolled and polished, to give it a regular and agreeable external appearance. Wax-tapers are made in a remarkable manner. The wick is unwound from a cylinder or drum, and rewound upon another cylinder, and in its passage from the one to the other it passes through a vessel containing melted wax, which wax thus gives a coating to the wick; but before reaching the second cylinder the taper passes through a hole in an iron plate, which makes it cylindrical, and of a uniform thickness throughout. The kind of candles called 'spermaceti' are made from a peculiar liquid found in the head of the sperm whale. Spermaceti is rendered solid when it reaches England, and can therefore be made into candles, but it is more costly than the whale-oil employed in lamps.

13. The most important candles, however, are those made of cheaper substances, such as tallow or palm-oil, on account of the immense quantities manufactured. Tallow candles present two chief varieties, called *dips*

and *moulds*, so named from the manner in which they are made. The wick is a loose kind of cord, made of a dozen or more cotton threads slightly twisted. It is brought from the Lancashire cotton districts in balls of three or four pounds weight. By an ingenious contrivance, the wick requisite for one candle is doubled over a stick and hangs downward: the loop at the top of the common dip candle marks the spot at which it had been doubled over the stick. As many wicks are hung upon each stick as will make about two pounds of candles, and they do not leave the stick until they have been properly coated with tallow. The tallow employed is chiefly the fat of cattle. In respect to our English oxen, by the time the butcher has been supplied, there is far too little fat left to furnish us with soap and candles. Russia is the country which chiefly supplies us with tallow; we buy considerably more than half the tallow which that country can spare for exportation. In the year 1853 England imported 1,178,370 cwts. (more than 130 million pounds) of tallow, chiefly for making candles and soap. When the tallow is to be employed for dip-candles, it is melted in a square trough by means of fire or steam. The dipper takes three sticks, or *broaches*, as they are called, between his two hands and dips all the wicks into the melted tallow; after two or three dippings he hangs them up to cool, and then takes three others. Thus he proceeds until a large number of wicks have received their first coating. When hardened they receive a second coating, then a third, and so on. According as the candles are to be large or small, so do the wicks consist of a greater or lesser number of threads, and receive a greater or lesser number of coat-

Fig. 1.

ings of tallow; the 'tens' more than the 'twelves,' the 'eights' more than the 'tens,' and so on. A 'twelve' candle (of which twelve make a pound) is dipped about twelve times.

14. But there has been a machine invented, which dips the candles much more rapidly. About two dozen wicks are hung on each broach; thirty broaches are ranged side by side in a frame; and thirty-six of these frames revolve round a central axis. When filled the machine thus contains more than 25,000 wicks. Each frame is brought in turn over the vessel of melted tallow, 700 or 800 wicks are dipped at once, and the frame is then moved on to make room for another. One man and a boy can make 20,000 or 30,000 candles in a day with the aid of such a machine.

LESSON II.

MOULD CANDLES.

1. In *mould* candles, as is well known, the outer surface is more regular than in dips; the wicks, too, are better twisted, and the tallow is generally of a slightly superior quality. The moulds are usually made of pewter, but in recent years glass moulds have come occasionally into use. When mould candles are made by hand, about a dozen moulds are ranged in a row, bottom uppermost, in a wooden frame, having a shallow trough at the top; a wick is carried down the centre of each mould, and is kept fixed in that position; melted tallow is poured into each mould, and the moulds are removed to cool in the open air. When cold, the superfluous tallow is removed, the candles are drawn out of the moulds, and are allowed to remain several months to bleach or whiten before they are sold.

2. For mould candles, as well as dips, machines have been invented which greatly expedite the manufacture. A machine of much complexity and beauty is

now employed in all the principal candle factories, for making mould candles. The wick is not cut off to the length of a mould, but is wound upon a reel, containing about a hundred feet to each mould; several moulds are ranged in a frame, each with a wick passing through it; the moulds are filled with melted tallow by a self-acting apparatus; the frame is wheeled along a kind of miniature railway to a distance, and another frame brought forward to be treated in a similar manner. When the candles are cold, one ingenious piece of apparatus cuts off all the wicks to a proper length, and another dexterously thrusts the candles out of the moulds. There is a double line of railway, the newly-filled moulds travelling along one line, and returning along the other to be finished, the length of railway being so calculated that the tallow shall solidify by the time each frame returns to the front of the machine. The very movement which thrusts out one set of candles from the moulds, draws in the wicks for another set. In Price's candle-works, presently to be noticed, when the whole of the machines are fully filled and provided for working, they contain wick for *five hundred miles* of candles!

3. Until about forty years ago no one sought to separate tallow into its component parts, and to employ some of these only in making candles: the tallow was used in its complete form. About the year 1813, however, M. Chevreul, an eminent French chemist, commenced a long course of investigation on this subject, and he gradually discovered that tallow is separable into four substances. He called these *glycerine*, *margarine*, *stearine*, and *oleine*, from four Greek words, signifying respectively 'sweet,' 'pearly,' 'solid,' and 'oily,' denoting certain qualities possessed, or certain appearances presented, by the four substances. He further discovered that glycerine is not combustible, and that it does more harm than good to candles; hence it became important to adopt some means of separating glycerine from the other three components of tallow. About the year 1832 French

manufacturers began to make candles of tallow deprived of its glycerine; and between the years 1832 and 1840 many manufactories of stearine candles were established in France and England, tallow being still the chief ingredient employed.

4. In 1836 an important change was made by the introduction of *palm-oil*. This oil is extracted from the fruit of trees growing abundantly in Africa; it is liquid in the hot climate of Africa, but becomes solid in the cooler climate of England. Palm-oil contains all the requisite ingredients for stearine candles, and it becomes simply a question of price whether palm-oil or tallow be the cheaper and better for the purpose. But this was not the only novelty. While some persons were experimenting on palm-oil from Africa, others were paying attention to cocoa-nut oil from Ceylon. In 1829 a patent was obtained for a method of obtaining stearine from this last-named oil, and candles from this stearine began soon afterwards to be made.

5. The most important operations in England, in this branch of manufacture, are carried on by 'Price's Patent Candle Company.' This company have purchased 1,000 acres of cocoa-nut plantation in Ceylon, to insure a steady supply of cocoa-nut oil. The oil is obtained from the kernels, which are dried, crushed under heavy stones, and then pressed until the oil is squeezed out. So large is now the demand for cocoa-nut oil in England, that 160,000 tons were imported in 1853. The candles made from the stearine of this cocoa-nut oil required snuffing;—this was considered to be a disadvantage; but the evil was remedied by the introduction of wire into the wick.

6. In the preparation of the materials for the candles, the palm-oil and cocoa-nut oil pass through many chemical processes, which require much care and attention. Steaming, decomposing by sulphuric acid, and distilling, drive off the glycerine; while pressing expels the oleine. The palm-oil is first of an orange-red colour, about the consistence of butter; it then becomes almost

black, and very hard; after distillation it assumes a state suitable for cheap candles; and, after further preparation, it is fitted for the best kind of 'Belmont sperm candles,' as they are called. The driest, whitest, and purest stearine (or, as it is now more usually called, stearic acid), which has been both distilled and pressed, is employed for the 'Belmont sperm.' Another kind, called 'Belmont wax,' is the same material simply tinged with gamboge, to give it an imitative wax appearance. A third quality is that which results from a mixture of cocoa-nut oil stearine, with palm-oil stearine. Commoner candles are made from palm-oil after the glycerine has been separated, but without pressure.

7. The manufacture of these several kinds of candles, at the Belmont Works (the Company's factory at Vauxhall) is very interesting. The prepared stearic or composite material is spread, by a machine, upon mats made of cocoa-nut fibre; several such mats are piled one upon another, and are subjected to intense pressure in a range of hydraulic presses; the oleine is squeezed out, and is sold for dressing woollen cloth in the clothing district of Yorkshire. The remaining solid substance is removed from the mats, and, after a little further preparation, is made into candles. All the Belmont candles are 'moulds,' none being made by 'dipping.' Very little tallow is used at this establishment; the stearic material being mostly obtained from palm-oil and cocoa-nut oil. So large has the use of these vegetable oils now become, in the manufacture of candles and soap, that Great Britain imported 636,628 cwts. (more than 70,000,000 pounds) of palm-oil from Africa in the year 1853.

8. LIGHT FROM LIQUID SUBSTANCES.—Nature has been still more bountiful to us in the supply of liquid combustibles for lamps than solid combustibles for candles. The number of vegetable substances which yield oil of a fat and unctuous character, either in the seed or in some other part of the plant, is very large. Linseed, hempseed, nut, poppy, olive, almond, beech,

rapeseed, castor, ground-nut, colza,—these are only some among many vegetable products whence oil may be obtained. The animal kingdom displays its bounty in the same way: the whale, the seal, the pilchard, and other dwellers in the waters, contain much oil which may be used to feed lamps; and certain land animals also yield oil. The mineral kingdom, too, aids in furnishing a supply; for many kinds of tar, pitch, naphtha, petroleum, and asphalte, obtained from particular spots on the earth's surface, are very rich in hydrogen and carbon.

9. The kind of oil used for lamps in any particular country depends upon the ease and the lowness of price at which it can be procured. We, in England, for instance, employ whale-oil rather than linseed, not only because it burns better, but because a large supply can be obtained at a lower price. Some nations, according to their geographical or commercial position, find it easier to obtain seal-oil than whale-oil, while others make use of pilchard-oil. Among plants the variety of sources is more considerable. A beautiful light can be obtained from a kind of wax derived from the *Virginia myrtle*, by boiling the berries in water, and skimming off the wax which rises to the surface. The seeds of the *arachis* or ground-nut contain a beautiful oil; as do also those of the *sesamum*,—the seeds, in both cases, being subjected to pressure. The Chinese *tallow-tree* yields, when its fruit is treated by a particular process, not only an oil fit for lamps, but a kind of tallow suitable for candles. The *olive* is, perhaps, more valuable than any of the plants above-named, in respect to its oil; for the source of supply is very abundant, and the oil is suitable both for cooking and for lamps. In warm countries the fruit of the olive is gathered from the trees, as apples would be in England, when properly ripe; the olives are spread out to dry, then reduced to a pulp, and then pressed in sacks: the oil exudes through the meshes of the sacks, and is collected in vessels — the quality becoming more and more

deteriorated as the pressing continues. In France and Belgium a large quantity of *colza*-oil is used for lamps; and in England also the use of it is gradually becoming considerable. In Paris there is much use made of *poppy-seed* oil and *rape-seed* oil, for lamps; while in the southern part of France, *grape-stone* oil is not unfrequently employed.

10. The kind of whale which yields ordinary lamp-oil is captured chiefly in the northern parts of the Atlantic and Pacific Oceans, and the gulfs and bays which open into them. The blubber, which yields the oil, and which is the most valued part of the whale, is the fat of the animal, varying from eight to twenty inches in thickness. All this blubber is cut off and lifted into the ship; the whalebone is likewise removed; and the rest of the unwieldy mass is allowed to float away. On shipboard the blubber is cut up into small pieces, and packed closely in barrels. At Hull, and at other ports in Great Britain, there are establishments in which whale-blubber is melted down into oil: the blubber is emptied into large vats, where it is melted, boiled, and otherwise treated, until lamp-oil is produced from it. A Greenland whale, of full size, averages sixty feet in length, and yields no less than twenty to twenty-three tuns of oil, weighing 40,000 to 45,000 pounds.

11. The Greenland or northern whale just noticed yields common *lamp-oil;* but *spermaceti* and *sperm-oil* are obtained from the southern or sperm whale. The sperm whale is the larger of the two, and its capture more difficult. The oil is obtained in the same manner from the blubber of both species of whales. Spermaceti is not only a remarkable substance in itself, but its use to the animal has never yet been satisfactorily accounted for. There is a large triangular-shaped cavity in the right side of the head: this cavity, while the animal is alive, contains about a tun or ten barrels of an oily liquid, which is fluid spermaceti. When the whale-ship arrives at its port of destination, the spermaceti is pressed in hair bags, then melted in boiling water, and then

passed through a few more processes, until it finally appears as the white semi-transparent substance, which forms the spermaceti sold in the shops.

12. In northern countries where the seal is met with, this animal is captured for the sake of its oil as well as for its skin: the blubber or fat is boiled down, as in the instance of the whale, and *seal-oil* is obtained. *Pilchard-oil* is largely produced in Cornwall: the pilchard is oily, like the herring, but is of larger size; and the oil is expelled by pressure—a hogshead of pilchards yielding about five gallons of oil.

13. Thus it appears that the animal and vegetable substances which contain oil are made to yield that oil either by pressure or by heat, or by both. Let us now trace the modes of using the oil in lamps.

LESSON III.

OIL-LAMPS.

1. The actual burning of a lamp depends on just the same principles as that of a candle; for, although the wick is immersed, in the one case in a liquid, and in the other in a solid, it amounts practically to the same thing; for the tallow or stearine of the candle must become melted into a liquid before it can ascend among the threads of the wick. This ascent depends upon a property called *capillary* attraction.

2. In order to increase the vividness of a lamp-flame, the wick should be made hollow instead of solid. This was one of the most important improvements in the *Argand* lamp, so named from its inventor. The wick, in this case, is confined between two concentric tubes, with a small portion rising above the top of the tubes to facilitate lighting; and the oil also rises in the small space between the two tubes. There is an arrangement made for gradually raising the wick, to

replace the portion burnt away. The great value of the hollow or cylindrical wick consists in this—that the atmospheric air can gain access to every thread of the wick, which cannot be so effectually done when the wick is solid; and this more rapid supply of air augments the combustion of the hydrogen and carbon in the oil, thereby producing a more brilliant light. This brilliancy is also increased by the use of a glass chimney. The air contained within the chimney becomes heated by the flame of the lamp; it becomes lighter or more rarefied in consequence of the heating; it ascends rapidly in consequence of this rarefaction; the flame draws in more air to replace that which has been thus dissipated; and the combustion is made more rapid by this increased indraught of air. As a tall chimney to a manufactory makes the steam-engine furnace burn more fiercely, so does the glass chimney of a lamp enable the flame to burn more brightly.

3. A very convenient lamp for spreading light around the lower half of an apartment, is one that is suspended from the ceiling. The oil is contained in a ring-shaped reservoir surrounding the flame, very shallow in comparison with its diameter. The oil descends obliquely by two tubes from the reservoir to the lower part of the wick, and then ascends to the top of the wick. The oil is at the same level in the wick as in the reservoir; but as it naturally sinks in the reservoir by the feeding of the wick, the flame becomes by degrees insufficiently supplied with oil, and emits a dim light in consequence.

4. Lamps are sometimes made on a better principle, in which the oil is maintained a ta constant level in the reservoir, and, therefore, at a constant level in the wick. The oil is put into a vessel, which is then inverted in another or outer vessel; and by a judicious arrangement of valves and air-tubes, the oil flows from the inner vessel into the outer reservoir just as fast as it is required to feed the lamp; and hence the level of the oil in the reservoir remains constant.

5. When the reservoir is below the wick some contrivance becomes necessary to cause the oil to ascend from the reservoir to the wick. Some years ago a kind of lamp was invented called the *hydrostatic lamp*, in which the effect was obtained by the pressure of air upon the oil in two or three receptacles and several tubes; but the arrangement was too complicated to be useful. A more successful invention is the *mechanical* or *Carcel lamp*, named after the inventor. A spring is wound up at intervals; and while uncoiling, it presses two pistons alternately into two receptacles filled with oil, which oil is driven through valves into a tube that conducts it up to the wick of the lamp. The oil is constantly and gently overflowing at the top of the wick; but as it falls again into the reservoir, no injury results. These Carcel lamps give a brilliant light. Another variety of this class of lamps, having the reservoir below the wick, is the *moderator* lamp, emitting an excellent light, and less expensive than the Carcel. The oil is contained within the stand or support of the lamp, very near the bottom. A coiled helical spring is entirely immersed in the oil; the spring cannot move upwards, because a ledge of metal-work checks it; but it is connected at the bottom with a piston which exactly fits the circular reservoir containing the oil. The spring presses upon the piston; the piston presses upon the oil beneath it; this pressure forces the oil up a tube to the wick; and any waste oil falls down again into the reservoir. There is a little piece of apparatus, called in French the *moderateur*, and in English the *moderator*, which acts as a regulator: causing the oil to ascend to the wick in about equal abundance, whether the spring be tightly or loosely coiled; and it is this piece of apparatus which gives name to the lamp. There are two handles or knobs to be seen between the wick and the reservoir of every moderator-lamp; one

Fig. 2.

of these raises the spring and piston, and the other raises the wick.

6. In the *safety-lamp*, used in coal-mines, a wire-gauze surrounds the flame, to prevent contact with inflammable gases in the mine.

LESSON IV.

LIGHT FROM GASEOUS SUBSTANCES.

1. The lighting of a large city, by means of gas—conveyed through hundreds of miles of underground pipes—is not the less wonderful and admirable because it has become familiar.

2. In this, as in most other great improvements, many minor attempts were made before complete success resulted. In 1659, a correct guess was made by a Mr. Shirley, that gas from coal-beds caused the production of a burning-well at Wigan, which at that time attracted much attention. In 1688, Dr. Clayton produced a jet of burning gas, by distilling coal in a small retort or confined vessel. In 1770, a colliery explosion, near Whitehaven, drew public attention again to the subject; and Dr. Hales and Dr. Watson did as Dr. Clayton had done before them, in producing jets of gas from coal. In 1786, Lord Dundonald proceeded so far as to construct a small gas-apparatus in his own house, as a matter of amusement. In 1792, Mr. Murdock lighted his own house with gas, at Redruth, in Cornwall. In 1802, the same gentleman, who was an engineer in the employ of Messrs. Boulton and Watt, lighted up the Soho factory at Birmingham with gas, on the occasion of a general illumination. In 1804, Messrs. Phillips and Lee's cotton-factory at Manchester was lighted with gas, being the first structure in which this mode of illumination was established as a general and permanent system. About the same time, Mr. Winsor published a prospectus of a 'National Light and

Heat Company,' gas being the agent by which the light and heat were to be produced: the project was at first much ridiculed, but it led by degrees to the formation of a company, which became the forerunner of those now existing. In those days, just half a century ago, the means were not known by which gas could be purified: the gas used at Birmingham and Manchester was dirty, it had a disagreeable odour; it caused headache when used in close rooms; it soiled apartments and furniture: and owing to all these defects the inhabitants of London had for a long time a prejudice against it. Pall Mall was the first street in London lighted by gas; this was in 1807: and by degrees, as the manufacture became better known and appreciated, gas became introduced into other streets, and into public buildings and private houses.

3. In order to understand the nature of gas-light, it will be desirable to bear in mind that it is necessary to obtain *carburetted hydrogen*, a compound of carbon and hydrogen and a diluent: the object of the manufacturing processes is to drive out all the other ingredients existing in coal.

4. The first process consists in separating the gaseous from the solid ingredients of coal. The coal is thrown into a horizontal vessel called a *retort*, which is then closed up and heated from beneath. The retorts vary considerably in shape; some are made of clay, but the greater number are of iron; and they are generally about six or seven feet long. Some gas-works contain five or six hundred retorts, each of which will carbonize 150 lbs. of coal in six hours. The coal in the retort does not burst into a flame, because no air can gain admission to feed the flame; the coal becomes red hot, and the gases, separating from it, rise through a pipe fixed in the top of each retort, and ascend into a horizontal pipe called the *hydraulic main*. These gases comprise many kinds, all mixed confusedly; and there are also portions of tar, ammoniacal liquor, and sulphurous acid carried up into the hydraulic main. The sub-

stance left in the retort is *coke*, which is removed to make way for a new charge of coal. The contents of the hydraulic main have to undergo many processes before the gas will be suitable for gas-lighting. The tar and the liquid ammonia are drawn off into cisterns ready to receive them. The hot mixture of gases passes through a vessel kept cool by running water on the outside; it becomes cooled, and deposits vapour of tar and other vapours, which condense into a liquid and fall down into a vessel beneath. The cool gas next passes into the *purifier*, a vessel containing either dry lime or lime-water; the lime exerts a remarkable influence on the gas, absorbing the carbonic acid, the sulphurous acid, and many of the other compounds which would interfere with the luminous properties of the gas.

Fig. 3.

5. The residue or refuse from these several processes, once thrown away as useless, is every year becoming more and more valuable. A ton (2240 lbs.) of good coal is estimated to yield, on an average, about a chaldron (1494 lbs.) of coke, 12 gallons of tar, 10 gallons of ammoniacal liquor, and 10,000 or 12,000 cubic feet of gas. By using more familiar quantities, it will be easy to remember that a hundredweight of coal produces rather less than two bushels of coke. The coke occupies one-fourth more space than the coal had done, on account of becoming more porous or less dense. Coke is used in locomotive engines, and in many furnaces and fires where smokeless heat is wanted. About one-fourth of the coke made within the retorts is placed under the retorts to heat the next charge, and the rest

is sold. The tar is used as a paint for out-door palings, and as an ingredient in 'patent fuel:' it also yields coal-oil, coal-naphtha, and pitch, all useful for various purposes. The ammoniacal liquor is made to yield carbonate of ammonia (smelling salts) and sal ammoniac: and it is also much valued as a manure.

6. The distribution of gas through a large town is still more interesting than the mere manufacture. The gas, when made and purified, passes through a *station-meter*, which has a sort of clock-work connected with it to measure the quantity of gas passing through it in a given time. From the meter it enters the *gasholder*, an immense iron vessel closed at the top and open at the bottom, and resting in a larger vessel containing water; the gasholder rises nearly out of the water as the gas enters it, but its edge is always sufficiently under water to prevent the gas from escaping. It used to be considered a great achievement, in bygone years, to make a gasometer 40 feet in diameter by 24 high, and capable of containing 30,000 cubic feet of gas; but some of the gas companies have now gasholders of ten times this capacity. Some gasholders are telescope-shaped, having two or three enormous cylinders sliding one within another. It is necessary to have these large reservoirs of gas, else, when evening is approaching, and many thousand gas-burners are about to be lighted, there would be a deficiency of material. The gas flows out of the gasholders, and enters the main pipes which traverse the streets; the pipes are of cast-iron, made in pieces which are securely cemented together; the main-pipes in the large streets are the greatest in diameter; the others become less and less according to the quantity of gas which they are to convey. As a gas-burner is sometimes two or three miles or more distant from the works where the gas is made, the gas could not flow with proper strength to that distance unless it were urged or pressed by some regular force: this pressure is exerted by a particular arrangement of the gasholder, and is made to vary in degree according to the distance

of a district, and the number of lights to be supplied. A piece of apparatus called the *governor* assists in regulating the pressure of the gas.

7. When a shopkeeper or any other consumer is supplied with gas, he ought of course to pay the company who manufactured it according to the quantity consumed. But a question arises, how shall this quantity be determined? In the early days of the gas-system, the charge was so much per jet or flame, according to the number of hours during which it was kept lighted each day, and according to the size of the jet; but this is an inadequate method, because it offers an inducement to a dishonest person to consume more gas than he pays for, and gives an honest person very little opportunity of varying the quantity used according to his requirements. A better system is now followed, by the use of the *gas-meter*, one of which is usually kept by every gas consumer. The purpose of the gas-meter is to determine the number of cubic feet of gas consumed in a given time, leaving it to the consumer whether this quantity shall be large or small, and pointing out exactly how much he will have to pay for, at a given price per thousand feet. There are two forms of apparatus for this purpose, the *wet-meter* and the *dry-meter*, and each form presents many different varieties. The water-meter is a hollow drum, or cylinder, about half-filled with water and divided into compartments; the gas passes through it in such a way as to make the drum rotate, and a certain definite quantity is known to have passed through during one rotation; there is clock-work and dial-work attached, with hands to denote the number of hundreds, thousands, and tens of thousands of cubic feet of gas which have passed through the meter.

8. The brilliant display of gas in a modern shop-window depends greatly on the form and arrangement of the burner. The invisible gas passes through very minute holes in the metal, and is then ignited. Sometimes the burner is called a *cock-spur*, sometimes a *fish-*

tail, sometimes a *bat-wing*, sometimes a *swallow-tail*, according to the shape of the flame; and this shape depends upon the number and arrangement of the little holes. The size and shape of the glass chimney, too, exert quite as much influence on the lightness of a gas-flame as on that of an oil-flame.

9. How astonishing is the magnitude of the supply of gas in London! The mind becomes almost bewildered in the attempt to appreciate such vast quantities. A few years ago it was roughly calculated that the quantity of gas made in and near the metropolis annually, cannot be less than 3000 millions of cubic feet: this quantity would suffice to fill 40,000 balloons as large as Mr. Green's "Nassau balloon;" or it would fill a gasholder as large as the city portion of London, and 100 feet high! Even before the Great Central Gas Company began to establish their works in London in 1851, there were no less than 2400 miles of iron gas-pipes beneath the streets of the metropolis, averaging (large and small together) about five inches in diameter; there were 1500 miles of streets thus supplied; but as 900 miles were doubly supplied by different companies, it made a total of 2400 miles. These streets are spread over an area of 66 square miles, of which the city of London only covers about one square mile—so enormously has the metropolis grown beyond the limits of the ancient city. The one square mile in the city contained, before the year 1851, about 75 miles of gas main-pipe, a much greater ratio than 2400 for the whole of the metropolis, on account of the density with which the shops and warehouses are packed together in the city. There were about 2700 public or street lights in the city; and about 60,000 in the whole metropolis: each of these burns about five cubic feet of gas per hour. All the various metropolitan gas companies together consume not less than 1000 tons of coal on an average every day.

10. But the other large towns in England have not been idle while this astonishing advance has been

making in London. Mr. Rutter made a rough guess, in 1848, that the various gas-works in the United Kingdom have cost 10,500,000*l.* in building; that they consume 1,125,000 tons of coal annually; that with this coal they produce 9000 millions of cubic feet of gas; that this quantity would fill a gasholder two miles in diameter, by 100 feet high; that the charge for the gas is about 1,600,000*l.* a-year; that the light given is equal to that from 350 millions of pounds of mould 'sixes,' valued at 11,500,000*l.*, or to that from 33 millions of gallons of sperm-oil, valued at 13,000,000*l.* If these numbers were nearly correct in 1848, they must be much higher at the present time.

LESSON V.

MISCELLANEOUS LIGHTS.

1. ALTHOUGH a candle, an oil-lamp, and a jet of street-gas, are representatives of the three principal kinds of artificial light, there are yet very numerous contrivances more or less in use, the peculiarities of which are interesting, and merit a little notice.

2. *Palmer's patent candles* and *candlesticks* are among the most useful modern inventions connected with artificial lights. The candles are welcome because they require no snuffing; and the candlesticks are welcome because they maintain the flame always at an equal height from the table. A candle-wick, while burning, gives off all its hydrogen and much of its carbon; but there is a residue which constitutes the 'snuff;' and it is this troublesome snuff which so frequently requires the use of snuffers, for the light becomes dim when the snuff becomes long. If the end of the wick can be made to bend out to the surface of the flame, the action of the atmosphere will gradually dissipate it without snuffing; and this object is now attained in Palmer's and other candles. In

Palmer's candlesticks there is a coiled spring beneath the candle; this spring presses upward, and keeps the top of the candle constantly up to the brass cap which covers it; if this cap were removed, the candle would spring altogether out of its receptacle.

Fig. 4.

3. Some of the 'night-lights' belong to the solid or candle class, rather than to the liquid or oil class. No part of the great Vauxhall candle-works is more striking and interesting than the department in which these humble productions are made. A night-light is simply a bit of candle, fit to emit a small flame in a sick-chamber or other apartment during the night; and yet the manufacturing arrangements have called forth a vast amount of ingenuity and capital. There are three kinds of night-lights *in most general use*—Albert's, Child's, and Price's. In the *Albert Night-lights*, melted tallow or fat is poured into a number of holes in a metal-plate, perhaps about an inch in diameter by an inch deep; there is a stem in each hole. When the tallow is cold, all the little castings are thrust out; each appearing like a small piece of candle with a hole through the middle. Children, in the meantime, have been preparing small wicks stiffened with wax; these are inserted in the holes, and fixed with amazing rapidity. The night-light is placed in a glass or tumbler for safety, and will burn from six to ten hours, according to its size. In *Child's Night-lights*, the material, instead of remaining exposed on the outside, is enclosed in a pasteboard box, something like a large pill-box. The making of these little boxes is, in itself, one of the prettiest operations in the factory. The kind of fat employed, and the mode of arranging the wick, are influenced by the size of the box into which the fat is poured. In using these lights, the box is dipped to a small depth in water, for security. In *Price's Night-lights*, the arrangement is nearly the same as in those just described,

but the materials are inferior, and the selling-price lower.

4. The *spirit*, and *naphtha*, and *camphine* lamps have given rise to many ingenious contrivances and arrangements. Spirit of wine, or alcohol, although used occasionally for lamps, is better fitted to produce heat than light; and thus it is used in spirit-lamps for chemical experiments, in Soyer's "Magic stove," and in other lamps intended for heating rather than lighting. Naphtha and camphine, however, are good light-giving materials. The "Victoria" lamp, the "Gem" lamp, the "Vesta" lamp, the "Paragon" lamp, the "Imperial" lamp, and many others to which particular names have been given, are all camphine lamps, differing in some mechanical peculiarities. Camphine, whether prepared from turpentine, or tar, or naphtha, is more combustible than oil, and hence yields a more brilliant light; but it requires much more care in arranging and using, and hence a camphine lamp is not always free from danger.

5. When the trigonometrical survey of Ireland commenced in 1824, Lieutenant Drummond, one of the officers employed, sought for some mode of producing a brilliant light which should be visible at a great distance, and thus serve as a station signal: he adopted Mr. Gurney's suggestion of the *lime-light*, and managed it in the following way. The flame of a spirit-lamp was fed with a jet of oxygen gas, and was directed upon a small piece of lime not larger than a boy's marble, and placed in the focus of a highly-polished reflector; the lime became heated to a degree of whiteness quite extraordinary; it did not emit flame, but it shed forth rays of light, which were visible to a greater distance than any light before produced by the ingenuity of man. A little marble of lime, heated in this way at Belfast, was rendered visible at an elevated station near Londonderry, 67 miles distant in a straight line. On a later occasion, three lime-lights were exhibited, one at Antrim in Ireland, one at Ben Lomond in Scotland,

and one at Kirkcudbright, also in Scotland; and although these three stations were distant respectively 76, 81, and 95 miles in straight lines, each light was visible from each of the other stations.

6. A novelty which attracted much attention a year or two ago is *water-gas*. Water consists of oxygen and hydrogen; hydrogen is one of the chief ingredients in coal-gas: chemists can readily extract the hydrogen from water; and hence it has been supposed that water might supply an inexhaustible quantity of hydrogen for gas-lighting. But there is one great defect in water-gas. Hydrogen yields much heat, but very little light; the light being due chiefly to carbon. Various experiments have been made in combining water-gas with oil-vapour, tar-vapour, resin-vapour, naphtha-vapour, and other vapours or gases rich in carbon; and it is possible that useful results may one day be produced.

7. In the year 1852 an attempt was made to form a company for producing and supplying *vegetable-gas;* the gas being obtained by the application of heat to various vegetable substances; but from some cause or other, or probably from many combined causes, the attempt failed. The *portable gas*, brought forward many years ago, has entirely failed. Gas was made at an establishment suitable for the purpose, and was conveyed to houses or other buildings in large vessels carried in carts. But this slow, expensive, and somewhat hazardous mode of employing gas was abandoned when the plan became general of conveying gas under the surface of the streets in main pipes.

8. Another remarkable novelty is the *electric light*. In 1846 a method was invented of applying an electric current to ignite a small piece of carbon or pure charcoal. In 1847 this method was so far perfected as to enable the inventors to exhibit the electric light on Hungerford Bridge, at the Polytechnic Institution, in front of the National Gallery, on the Duke of York's Column, and in other parts of London. There was a

galvanic battery to produce the power, there were two pieces of carbon to emit the light, and there was much delicate mechanism to enable the battery to act upon the carbon. In 1848 there were improvements made in the apparatus, both in France and in England. In 1849 there were still more numerous improvements; and Dr. Faraday, Mr. Grove, and other eminent chemists, made experiments on the subject. The years 1850 and 1851 witnessed many controversies and researches respecting the matter; and at one time very sanguine hopes were entertained of success; but since then the subject has gone somewhat out of favour; and at the present time the electric light is in abeyance —destined, perhaps, to be rendered useful by future inventions.

9. Since the introduction of gas for street lights, great ingenuity has been shown in new methods of producing gas, or of using it when produced. Mr. Gurney invented what is called the *Bude light*, so named from the town in Cornwall at which the inventor resided. Mr. Gurney thought that if the interior of the wick of a lamp was supplied with oxygen gas instead of air, it would cause the oil to burn with still greater brightness: this was done, and the first kind of Bude light was thus produced. But the difficulty of preparing and supplying oxygen gas rendered this method troublesome and expensive, and various alterations were made. The present Bude light, instead of being an application of oxygen gas to an oiled wick, is a peculiar arrangement of gas-burner, with a current of air acting upon a particular part of the flame. Mr. Gurney also introduced a method of improving the quality of coal-gas, by making it pass through a vessel containing naphtha.

10. Busy hordes of men are thus searching for whales, digging for coal, gathering palm-fruit and cocoa-nuts, navigating ships laden with tallow, and blubber, and oil, making candlesticks and chandeliers, fashioning elegant lamps, making gas in thousands of

millions of cubic feet, laying thousands of miles of iron pipes to distribute this gas, making candles, and tapers, and night-lights, and organizing a system of trading and dealing, necessarily involving the payment of vast sums of money, and the support of hundreds of thousands of persons—and all that we may be supplied with light during the hours in which the sun is below the horizon.

GEORGE DODD.

Arts and Manufactures.

INDIA-RUBBER AND GUTTA-PERCHA.

BY GEORGE DODD.

LESSON I.

INDIA-RUBBER.

1. FEW subjects are more worthy of attention than the application of the properties of natural bodies to useful purposes. No sooner does man become acquainted with a substance before unknown to him, than he seeks to investigate the qualities inherent therein, with a view to avail himself of any advantages accruing from his discovery. If a gum exude from the trunk of a tree, he inquires, Is it elastic? is it tough? is it readily soluble? may it easily be wrought into different forms? is it durable? will it resist the action of air and moisture, of gases and chemicals? may it be combined with other substances to vary the nature and degree of its service? All such questions as these have been put, and happily answered, in respect to two very remarkable gums which now occupy an important place in manufacturing and domestic economy. These are INDIA-RUBBER and GUTTA-PERCHA, to each of which a Chapter will be here devoted.

2. India-rubber, like many other substances in frequent use, has a name which no longer duly characterizes it.

A rubber, a means of rubbing out pencil-marks, is undoubtedly a useful addition to the implements for drawing and writing; but the substance thus named has acquired a much wider range of serviceable application, and it would be well if a more significant name could be found for it. The Indian name, *caoutchouc*, might advantageously be retained.

3. The history of the introduction of this remarkable substance into Europe is interesting. Some of its properties were known before the origin of the substance had been ascertained. The Spaniards had much intercourse with South America at a time when that continent was little known to Europeans generally; and among these Spaniards many appear to have acquired a slight acquaintance with the appearance and properties of india-rubber. One Spanish writer, towards the close of the seventeenth century, described a substance which the South American Indians designated *usquahuitl*. The natives, he tells us, made incisions in the trunks of certain trees, caused a gummy sap or juice to flow out, collected this gum in calabashes, allowed it to harden by exposure to the air, and then applied it to many useful purposes. It appears that they were acquainted both with the elastic and the waterproof qualities of the gum.

4. There can be but little doubt that the gum described as above was india-rubber, and circumstances gradually led to a further knowledge of this substance. In 1735, M. de la Condamine, accompanied by Bouguer and Godin, made a scientific journey into South America, under the direction of the French Academy of Sciences. Although their main object was to measure an arc of the meridian (with a view to the more accurate determination of the dimensions and figure of the earth), they did not neglect other subjects. Among the natural productions of Peru they noticed the gum of the india-rubber tree. There had before been seen in Europe grotesque figures of birds, animals, and other objects, formed of an elastic substance, and Condamine sought out the species of tree whence this substance was obtained. In the period

of a hundred and twenty years which has since elapsed, the india-rubber tree has been met with in Asia as well as in America; and trees of various species are now known which yield a gum similar in many particulars to india-rubber.

The true india-rubber of the tropical parts of South America is considered to be the juice of the *Siphonia elastica;* but juice of an analogous character is obtained from the *Ficus elastica*, the *Cecropia peltata*, the *Castilloa elastica*, the *Urceola elastica* of Sumatra, the *Vahea* of Madagascar, the *Willughbeia* of India, and the *Cynachum ovalifolium*. Wherever and from whatever tree obtained, the gum is collected by the natives in a rude and simple way. The trees are pierced during the rainy season, and through the perforations there exudes a thick yellowish-white juice. The colour and consistence of this juice change according to the mode in which it is treated: if the juice be kept well corked in bottles, it will remain liquid for a considerable time; if it be exposed to the air in thin layers, it will darken in colour, lose much of its weight by evaporation of moisture, and become dry and tough. The native collectors find the gum to be most useful in the state of layers, and they bring it to this state in a remarkable way. They make clay models of bottles, animals, grotesque heads, or any other objects; they apply the gum to the surface of these models as a kind of varnish, increasing the number of coatings according to the thickness required; they hang the varnished models over fires, the smoke of which tends to harden and blacken the india-rubber; they impress any fanciful devices upon the surface by means of blunt tools; and finally, by crushing and shaking out the clay, they liberate the india-rubber as a kind of hollow cast from the model. It is in this state that india-rubber generally reaches England: the wholesale dealers purchase these hollow masses from merchants in tropical countries, and the manufacturers repurchase with a view to bring the gum into various useful forms.

5. The modern manufacturers have not so much discovered new properties in india-rubber, as invented new processes to render the substance valuable in every-day life. The South Americans are, and have been for centuries, acquainted both with the elasticity and the waterproof quality of the gum. They make waterproof boots of india-rubber—they apply the liquid juice to coarse cloth as a means of rendering it impervious to moisture—they avail themselves of the elasticity of the gum in making some of their weapons of offence—they make flambeaux or candles of long pieces of the gum—they make of it elastic balls for game-play—and they extract from it an oil useful in medicine. When Europeans began to be acquainted with the various properties of the gum, its wonderful elasticity could not fail to excite attention. Probably no other known substance equals it in this respect. If a piece of india-rubber be soaked in warm water, it may be stretched to seven or eight times its former length without interfering with its power of contracting to the original dimensions when cold; if air be forced into an india-rubber bottle, the bottle may be swelled out to a large size; and if first rendered soft by steeping in sulphuric ether, the bottle may be blown out so thin as to be transparent, and converted into a globe four or five feet in diameter.

6. The chief uses of this valuable substance may be considered as of three different kinds—a *rubber*, an *elastic* material, and a *waterproof* material.

The employment of a piece of india-rubber to erase pencil-marks does not appear to have become general until seventy or eighty years ago; for Dr. Priestley, in the preface to his work on 'Perspective,' published in 1770, states that, since the printing of his volume, he had met with a peculiar substance "excellently adapted to the purpose of wiping from paper the marks of a black-lead pencil." It was india-rubber to which he referred; and he further stated that Mr. Nairne, a celebrated mathematical instrument maker of those

days, sold the substance at a price of three shillings for a cubical half inch. This, it will be seen, is a very high price, indicative of the substance being limited in quantity and difficult to procure. The india-rubber is required to be of very good and equable quality, to fit it for the erasure of pencil-marks. Very recently an article has been invented in America, and brought to England for sale, called the 'Ink-eraser and paper-cleaner;' it is in pieces about an inch and a half long, an inch wide, and a quarter of an inch thick, and is grey in colour. It appears to be a compound of india-rubber, with pounded emery or some other hard gritty material. The object of the inventor seems to have been to produce a compound in which the india-rubber may remove pencil-marks and dirt, and the gritty particles remove ink-marks: to some extent this object has been attained, but not so fully as is implied by the inventor.

7. In rendering india-rubber fitted for use as an elastic material many processes are necessary, for the gum generally reaches England in a very impure state. The india-rubber is cut into small pieces, washed in warm water, dried, and pressed or worked about in a kind of kneading machine: the substance becomes very hot during the kneading, and all dirt and moisture are thoroughly forced out. The smooth dark-coloured mass is then subjected to intense hydraulic pressure, which brings it to the state of blocks, slabs, or cylinders, convenient for subsequent operations. Different patentees adopt different modes of purifying the india-rubber; but washing, kneading, and pressure are always necessary.

8. The cutting of the prepared india-rubber into sheets, ribbons, and threads, is ingeniously managed. A cubical block of india-rubber is shifted onward through small distances equal to the required thickness of the sheets, and some kind of sharp cutting instrument severs it slice after slice. From these sheets pipes or cylinders may easily be made, by drawing a sheet between two

rollers, and then wrapping it round a wooden roller, it will cohere firmly into a tube by the softening effect of the heat produced during the process. When a cylinder is thus made, it may be cut into a continuous tape or ribbon by a cutting-machine which works spirally around it; or a ribbon may be produced from a flat circular piece, by cutting it spirally from the circumference to the centre. These ribbons are cut into threads or very narrow filaments, by revolving circular knives placed at such a distance apart as will correspond with the required width of the threads.

9. The applications of blocks, slabs, cylinders, ribbons, and threads of india-rubber to elastic purposes are now so extremely varied and numerous, that it is scarcely possible to give them in detail. The following enumeration will illustrate the most important and interesting of these uses:—

(1.) Short elastic tubes for chemical purposes, for connecting two pipes together, for instance, are readily made from a sheet of india-rubber: a short piece is wrapped round a roller or stick of proper thickness, the superfluous portion is cut off, and the newly-cut edges of the piece adhere to each other firmly by the aid of a little pressure. (2.) Where it is necessary to protect the feet of horses from injury, a pavement of india-rubber combined with other materials is sometimes made for stables; and lobbies and halls have also been paved with it. At Woolwich Arsenal, at the Admiralty Court-yard, and at Windsor Castle, pavements have been made of this character. (3.) The elastic property of india-rubber has been applied to projectiles, by adapting a kind of elastic string to a hollow tube, in such a way as to propel an arrow with great velocity. (4.) A mode has been devised of applying the same power to tackle or pulleys for mechanical force; by making the cords of the tackle elastic instead of unyielding, means are thus afforded of accumulating power, and bringing it to bear with great effect on any one point. (5.) Saddles and collars for horses have occasionally been

made of india-rubber, for which it seems well suited on account of its elasticity. (6.) Springs for doors are very usefully made in this material. (7.) Bands, bandages, and rings, for fastening or confining papers and other small articles, are now made in immense variety; any one who sees how readily an inch circle may be stretched out to two or three inches in diameter, and then brought back to its former size on removing the stretch, will at once appreciate the exhaustless diversity of application which india-rubber possesses for this purpose. (8.) Maps and prints are now printed on sheets of india-rubber as thin as fine writing-paper: the elasticity of the material renders these maps and prints more durable than those printed on paper. (9.) Tires for 'noiseless wheels' are made of india-rubber, the tire rolling over the ground with a soft springy motion unaccompanied by noise. (10.) Bearing-springs for carriages, and buffers for railway-vehicles, are gradually coming within the range of the useful applications of india-rubber. (11.) Sewer and sink-traps are serviceably made of this material, as are likewise flanges and socket-joints for pump-work. (12.) Stoppers or stopples for bottles and decanters, made of india-rubber, have a degree of elasticity which enables them to close the vessels very securely. (13.) Surgical bandages made of this material are invaluable, for they accommodate their position to fractured limbs or diseased parts most admirably; nor is india-rubber less useful in making many of the small tubes and apparatus required by surgeons. (14.) India-rubber floor-cloths, of considerable size and printed in lively colours, are made in the United States. (15.) The same industrious country produces india-rubber globes, so thin that they can be inflated by the mouth. (16.) India-rubber veneers, painted on one side to imitate rosewood or some other ornamental wood, are prepared for application to articles of household furniture. (17.) India-rubber milking apparatus for the dairy is not among the least remarkable of the modern application of this substance.

10. Some of the many articles enumerated in the last paragraph, and others not yet mentioned, require the india-rubber to be in the *vulcanized* state. This vulcanization is interesting, both from the mode in which it is conducted, and for the effects which it produces. The product obtained is in fact a compound of india-rubber and sulphur. When sulphur is melted, india-rubber exposed to its action undergoes a remarkable change; it becomes carbonized in appearance, and if the heat be great, the consistence becomes almost horny. The skill of the manufacturer is shown in employing such a degree of heat, and in so conducting the process, that the exact product shall be obtained which constitutes 'vulcanized india-rubber.' The altered substance is rendered stronger, more permanently elastic, more insoluble in essential oils, and better able to bear variations in heat and cold without losing its elastic power, than in its original state. With this compound substance many remarkable and useful articles are now made. Its power of resisting compression is such that a cannon ball has been broken in fragments by being fired into or through a mass of vulcanized india-rubber. Many ornamental articles are made in this material by being cast in moulds, since the elasticity of the india-rubber enables it to accommodate itself to any amount of relief in the design. Inkstands, presenting a soft bedding for the point of the pen to encounter, are made of this vulcanized substance; and many of the bands and springs mentioned in the last paragraph are similar in material. Its imperviousness fits it for use in bottles for containing volatile liquids. Little cushions beneath the legs of chairs and in the grooves of doorways, made of this substance, tend to the prevention of many harsh noises. Vulcanized india-rubber placed between the rails and sleepers lessens the concussion and wear occasioned by railway transit. An air-gun, without air-pump, reservoir, or valves, has been constructed, in which a small piece of vulcanized india-rubber is the chief agent of power. A piston in a cylinder is suddenly acted on by

an india-rubber spring, and as suddenly condenses the air in a small chamber; this air forcibly propels a bullet from the gun with force enough (it is said) to flatten the bullet against a metal target. Balls, whips, and numerous other toys are largely made in America of vulcanized india-rubber; and American ingenuity has even devised the mode of making flutes, combs, and walking-sticks of the same material. Inking-rollers for printers, usually made of a composition of glue and treacle, are now sometimes fabricated of vulcanized rubber. Billiard-balls exhibit another of its forms of application. It may be well to mention that some of the prepared india-rubber, whether called 'vulcanized' or not, contains magnesia, and some, carbonate of lead, instead of sulphur: it may, indeed, be mineralized by means of many different agents.

11. Besides the numerous applications already noticed, there are many singular and useful articles in which india-rubber is employed as a thread combined with other threads. The other threads may be silken, woollen, flaxen, hempen, cotton, or hair, thus giving use to a great diversity of materials; and the saleable objects produced from these materials are not less diverse in character. Braids, braces, belts, cords, sandals, shoe-springs, glove-springs, shirt-collar fastenings, umbrella-ties, garters, corsets, bandages, armlets, wristlets, watch-guards, bead-threading, neck-chains, and various substitutes for buttons, buckles, strings, pins, and hooks-and-eyes are now made of this material, and sold in extraordinary quantities. There would, perhaps, scarcely be found a person in the middle ranks of society in England whose attire did not at the present time comprise some article or other made of india-rubber, or containing india-rubber combined with other materials. Many processes are adopted in the manufacture of these articles. A machine has been invented whereby one pound of india-rubber may be cut into 32,000 yards (more than eighteen miles) of thread, and another machine will cover this thread with silken thread. In weaving

elastic cloth, an ample choice is afforded for varying the degree of elasticity: the warp and the weft threads may all be elastic; the warp may be elastic and the weft non-elastic; the warp may be elastic while the weft-threads may be alternately elastic and non-elastic; differences that would effectually vary the purposes to which the cloth would be practically applicable. And in speaking of cloth, it is not here meant to limit the remarks to broad fabrics; ribbons, tapes, braids, bands, laces, cords, all can have their elasticity determined by the degree in which india-rubber is combined with other fibrous substances. In most of the articles produced, the non-elastic threads are puckered or crumpled in order that they may accommodate themselves to the stretching which the elastic threads are expected to bear.

12. It is difficult to say whether the elastic or the impermeable quality of india-rubber be the more valuable. Both render such services to man that they are equally worthy of our attention. The foregoing account of the uses of india-rubber in virtue of its elasticity may now fittingly be followed by a description of its waterproofing application.

To render woven cloth waterproof and airproof was an object of solicitude long before india-rubber became employed for this purpose. One method of obtaining this result was to steep the cloth in a solution of alum, whiting, and water, and then pass it through soapy water. Another method was to steep the cloth in a solution of white lead and alum, then in a solution of quicklime, and lastly in a mucilaginous solution of boiled Irish moss. A third plan consisted in brushing over the reverse or under-side of the cloth with a solution of isinglass, alum, and white soap, the intention being to render the cloth waterproof but not airproof. In a fourth method a paint or varnish was applied to the cloth, composed of linseed-oil, pipeclay, pumice, and one or two other substances, to impart a waterproof character to tarpaulins, awnings, coach-top covers, and

boat-cloaks. Other methods have been proposed for rendering cloth waterproof by a composition applied to one surface, while the other surface was so shielded during the process as to retain its ordinary appearance.

13. But all these attempts—except the application of oil or varnish to the commonest kinds of goods—have been superseded by the superior usefulness of India-rubber as a waterproofing material. It was just about thirty years ago that a patent was obtained for a mode of preparing a material for hats and bonnets, in lieu of felted cloth or beaver; there was to be a mixture of beaver-fur, musk-fur, hare's-fur, Spanish-wool, flax, down, and waste silk—any or all of these combined; the mixture was to be carded, roved, and spun; the spun-yarn was to be soaked in a solution of india-rubber, and woven when dry; and the cloth when woven was to be drawn over a heated cylinder, whereby the gum would be melted and caused to fill up the interstices or meshes of the cloth. This was the object of the patent; but the process was very little adopted, for the superior plan invented by Mr. Macintosh came under public notice about the same time.

14. The dissolving of india-rubber was at first a matter of some difficulty. Chemists had to search long before they found a cheap and effective solvent. Petroleum, ether, naphtha, camphine, gas-tar, oil of turpentine, and many similar liquids, it is now known will effect this; and it is simply a question of price as to which shall be employed. One method of proceeding is—to place fragments of india-rubber in a vessel; to heat the liquid in another vessel until it passes off into vapour; and to allow this vapour to attack and dissolve the india-rubber. By this or some other method, india-rubber may be liquefied, and in that state applied to its various waterproofing purposes—of which the prepared cloth for garments is perhaps the best known.

15. The Macintosh cloth has come into widely-extended use. As first patented, it was prepared in the fol-

lowing way. The cloth, woven in cotton or any other material, was stretched upon a frame, and was brushed over with a cement or varnish made of india-rubber dissolved in coal-tar; the wetted surfaces of two such pieces were placed together, and pressed between rollers. The india-rubber solution thereby rendered two kinds of service—it cemented together the two pieces of cloth; and it formed a delicate film, impermeable to moisture. Messrs. Macintosh have patented improved processes in later years; but the principle of the double cloth continues to form the chief characteristic. Other inventors brought forward numerous ingenious methods of attaining the same object. One patentee had a plan of cutting up fibres of flax, cotton, hemp, wool, and silk, into fragments one-eighth of an inch in length: these he mixed with liquid india-rubber; the mixture was poured out upon a cold slab, hardened, rolled into a thin smooth sheet, and made up into shoes, gaiters, capes, cart-coverings, and other articles. Another plan was to moisten the surface of woven cloth with india-rubber solution; then coat it with a thicker composition, in which the same gum formed one of the ingredients; then sprinkle short fibres of wool, cotton, silk, or flax, upon the composition; and finally press these fibres down upon the cloth by rollers. The fabric thus produced was waterproof, but not elastic: the same inventor, however, produced another kind, which had an elastic quality; he cemented a thin sheet of india-rubber upon the surface of gauze or bobbin-net, and then cemented fibres upon this sheet. Many other ingenious processes have been invented; but the double cloth, with a cement of india-rubber between the two thicknesses, has superseded most other varieties.

16. The purposes to which this waterproof cloth is now applied are almost endless in number. Clothing, dwellings, vehicles of transport, manufacturing apparatus, wrappering, toys—all experience the benefit resulting from the use of a material which will not permit of the passage of water. Boats covered with

india-rubber cloth have been used in some of the Arctic expeditions. Surf-boats and safety-boats have been made with a similar provision. A pontoon-boat has been made nearly a hundred feet in length, and yet so light that its materials could be packed into a couple of carts; it consisted of a light wooden framework, covered with waterproof cloth.

17. The formation of buoys and buoyant garments, by the aid of waterproof cloth, has occupied much attention within the last few years. A life-cape has been invented, consisting of two thicknesses of india-rubber cloth, with a provision for forcing air into the intervening space. A yachting-jacket is another contrivance, so waterproof and so susceptible of being inflated with air, as to be enabled to support the wearer in the water. "Buoyant paletots" and "buoyant cloaks" have been made on a similar principle. A "safety-hat," has been invented, with a lining of waterproof cloth, intended to float the wearer when air is introduced within the lining. A cloak-boat of curious construction, has been brought under public notice; in its ordinary state it is a cloak, with a small pair of bellows in one pocket, and a small pair of paddles in the other; the wearer can blow air into the space between the double cloth of his cloak, and he thereby forms a boat in which he can paddle himself over the surface of the waters. Belts, pillows, cushions, mattresses, and beds have been invented in considerable variety, made of waterproof cloth, filled with air, and intended to aid in the preservation of life; but, principally from a general negligence in providing safety-apparatus, very few lives have been saved by any of these contrivances. It is in ordinary every-day uses that the value of waterproof cloth is most observable. Dr. Arnott's admirable contrivance of the "water-bed" owes all its efficiency to the use of waterproof cloth. "Portable baths," of very convenient form, are made of the same material. Waterproof cloaks, coats, capes, jackets, gloves, leggings, gaiters, and other garments, are now so numerous, that every one is familiar with

them. Letter-bags, cart-coverings, and gas-bags may be added to the list.

18. One of the most remarkable applications of india-rubber is for "over-shoes;" the waterproof quality renders them valuable in wet weather; while the elastic quality renders it easy to draw them on over other shoes or boots. These shoes are made in enormous numbers in the United States. Mr. Whitworth, in his Report on the New York Exhibition of 1853, says:—"The india-rubber, in its rough state, is first cut up by shears into small pieces. It is then put through a machine similar to that used for tearing and cleaning rags intended to be made into paper; the water used in the operation is drawn off from time to time through a wire grating. The material, thus chopped up and cleaned, is passed through rollers, where it is sufficiently ground; it is then put through other rollers, where it is kneaded and worked up with the necessary composition. The india-rubber, so mixed, is passed in the form of an endless web, through four rollers placed vertically one above the other, and comes out a broad web fit for use." Mr. Whitworth then describes how a sheet of india-rubber is united to the surface of a piece of cloth; and proceeds to say, "The india-rubber cloth is cut out from the sheet by workmen, in the shape required to form shoes. The parts so shaped are put together by women, who form them on lasts, closing the joints by cohesion, after touching them with camphine. Each woman finishes an entire shoe, and about 1400 pairs are made daily. [This refers to one factory alone.] The shoes are then covered with a coat of varnish, and taken to the stove-drying-room, where they are subjected to a heat of 250 or 280 degrees, and allowed to remain a night." The commoner india-rubber shoes are made in the way just described; the more expensive kinds are made entirely of the gum, applied in successive coatings, as a varnish to a last.

No one can glance through the above list of products

without seeing that human industry has been worthily employed in bringing the remarkable properties of india-rubber into profitable requisition. It will next be shown that the companion substance—*gutta-percha*—has equally excited the attention of those who minister to our every-day wants.

LESSON II.

GUTTA-PERCHA.

1. CONSIDERING that gutta-percha has been known in Europe during so short a time, the extent of its application is even more surprising than that of india-rubber. No longer ago than 1842 this remarkable substance was almost (if not wholly unknown) to Europeans. Dr. Montgomerie, a medical practitioner at Singapore, happened in that year to see a native Malay cutting wood in the forest with an axe having an elastic handle; and, on inquiry of the man, he found that the handle was made from a vegetable gum which could be fashioned into any shape when slightly warm, and would retain that shape when cold. He sought until he found the tree whence the gum was obtained; and he had the credit of sending to England the first specimen of gutta-percha. The Society of Arts awarded a gold medal to Dr. Montgomerie, and manufacturers immediately directed their attention to this new substance. It was soon found that gutta-percha possesses qualities analogous in some degree to those of india-rubber, but yet peculiar to itself in many respects; and its usefulness in manufactures became so obvious, that a desire began to be felt to know how far a supply might be depended on. It may be useful here to mention that *percha* is a Malay name, and that it is pronounced like *pertsha*, not *perka*.

2. Later explorers have ascertained that the gutta-percha tree flourishes in many parts of the East. Mr.

Lobb, a scientific botanist, met with it in some of the islands of the Indian Archipelago; and it grows in Borneo, on Sir James Brooke's territory of Sarawak. As soon as the English merchants began to offer a price for all the specimens which could be procured, the natives were stimulated to search for the trees and obtain the gum. The chiefs and the people had many disagreements concerning the mode in which the profit should be divided between them, and a wild excitement arose in the search for this new source of wealth. Government officials, Malays, Chinese, serfs or slaves, aboriginal islanders—all contrived to benefit in one way or other. One disastrous consequence was, that the natives recklessly destroyed the trees in their eagerness to obtain the gum—a new version of the old story of the golden egg. In Singapore, Penang, Java, Sumatra, and Borneo whole forests were swept away in this search for the precious gum. The wood, being soft and spongy, is not of much use; the fruit yields a little oil; but the sap is the only product which renders the gutta-percha tree especially valuable. The sap circulates in small vessels between the bark and the wood, and therefore incisions, made at the proper seasons and in a judicious way, will cause the sap to ooze out without any such wasteful course as felling the tree. Hitherto the existing trees have been amply sufficient to furnish a supply, but attempts are being made to ascertain whether the tree can be cultivated, so as to insure a continuance of gutta-percha plantations. The sap, as it flows out, is collected in vessels, and when it has solidified sufficiently to be handled, it is kneaded into lumps. The merchants at Singapore purchase these lumps at a price per pound, depending on the quality, and the gutta-percha is then shipped to England.

3. The manufacture of this gum into useful articles cannot be effected until the gum has undergone many purifying processes. Not only are there leaves, twigs, dirt, stones, water, and other matters, mixed accidentally with the gutta-percha, but the natives sometimes fraudu-

lently insert rubbish in the middle of the lumps, to increase the weight. All these extraneous substances must be removed before the gutta-percha will be in a state fit for manufacturing purposes. The lumps, when they reach the English factories, are cut into slices, by means of rapidly-revolving cutters; the slices are softened to a mass by steam; the mass is tossed about in a machine containing jagged spikes, in such a way as to liberate all the impurities, and cause them to escape; the mass is again softened, and is kneaded into a kind of dough-like substance. This substance is placed in a heated iron cylinder, and is so torn about and worked by revolving spikes as to become thoroughly smooth and homogeneous. In this state the gutta-percha is converted into blocks, slabs, cylinders, or sheets, preparatory to further applications; by being passed between steel rollers, it may be reduced to sheets of any required thickness; by being poured or pressed into moulds, it may be shaped into blocks or slabs; and by being forced through pipes of greater or lesser diameter, it may be converted into hollow tubes or solid rods.

4. At the Gutta Percha Company's works, in the City-road, numerous interesting processes are carried on for bringing the material into useful forms. One class of processes is that of cutting: sometimes a sheet is cut into definitely-shaped pieces, as for shoe-soles and heels; or into narrow cords or threads, to be used in various ways. Another class comprises the various moulding processes: the moulds are formed in wood or metal, and the gutta-percha is pressed into them while in a soft, warm state. The gutta-percha covering for electric wires is applied in a very remarkable way: several wires are laid down parallel on a sheet of gutta-percha; another sheet of the same substance is laid over them. The triple layer is passed between groved rollers, which press the gutta-percha close to the wires, and at the same time sever the covered wires one from another. This, however, is not the only mode of coating these invaluable wires: a plan has been devised of drawing

the wire through holes in a box containing paste-like gutta-percha, whereby a covering of the gum exudes with the wire itself.

Perhaps it will be a convenient mode of noticing some of the remarkable applications of gutta-percha, to group them according to the kind of service which they render—for our garments, for our dwellings, for articles of use and ornament, and for out-door purposes.

5. Gutta-percha is not employed as a subsidiary material in dress so largely as india-rubber; yet its uses in this respect are daily increasing. The qualities on which its uses depend are many. It is totally impervious to rain or moisture; it is not affected by salt water, or by the ordinary acids or alkalies; it is easily repaired by warming and rejoining the severed edges; it is very light, considering its great strength; it has a peculiar power of resisting frost; it conducts heat very slowly; it is an almost perfect insulator of electricity, and hence becomes invaluable as a covering for electric wires; it has an extraordinary power of conducting sound, which fits it for use in the construction of speaking-trumpets and hearing-tubes; it may be easily softened by heat, easily pressed while soft into any form, and easily cooled in the shape required.

6. There are now manufactured of gutta-percha pilot's caps and sou'-wester hats, well adapted for resisting the heaviest rains. Gutta-percha soles for shoes are much used during the winter. They are cheaper than leather; they keep out rain effectually, and if applied with a little care, they adhere well to the boot or shoe. Some of the police force wear soles of this kind. Gutta-percha is used, in thin sheets, for nursing-aprons, and as a lining for ladies' bonnets. There is one circumstance which limits, and is likely always to limit, the employment of gutta-percha near the person, either as a part of the dress or as an ornament, it becomes somewhat soft when warm and has then a tendency to lose its shape. There will, however, unquestionably be an extension in its use for personal purposes, and already the medical practi-

tioners find it a valuable ally in the sick-room. The pliability of gutta-percha when warm, the ease with which it can be adapted in that state to the contour of a limb, and its strength, when cold, render it valuable as a splint or support for club-foot, fractured limbs, &c., and many eminent surgeons now employ it for this purpose. In ascertaining the state of the lungs, physicians employ an instrument called a stethoscope—a tube through which the pulsations of the heart can be heard, and it is now found that gutta-percha is better than wood for this purpose, chiefly owing to the extraordinary readiness with which it transmits sound. Gutta-percha is found useful as a strapping for diseased joints. Liquid gutta-percha is employed in the treatment of some kinds of wounds. As a "merciful man is merciful to his beast," it is almost as much a duty to find comforts and conveniences for so noble an animal as a horse as for man himself. In this sense, a gutta-percha horse-shoe is not too humble to merit a little notice; it is not properly a shoe, but a covering of gutta-percha for the tender sunken portion of a horse's foot. Stones are apt to insinuate themselves into that sunken part, to the great discomfort of the poor animal, and it has lately been found that a useful shield may be made by applying a thin piece of gutta-percha while warm.

7. The fittings and conveniences of our domestic houses, made of gutta-percha, are more numerous than the articles for personal use. There are gutta-percha washing-bowls, water-jugs, soap-dishes, ink-bottles, inkstands, paper-weights, drinking-mugs, pen-trays. There are noiseless curtain-rings, plain and coloured window-blind cord and picture-cord, and clothes-lines made of the same material. There are bread-trays, biscuit-trays, work-table trays, counter-trays, card-trays, tooth-brush trays, shaving-brush trays; together with work-baskets, fancy-baskets, cushion-stands, watch-stands, light-stands, bread-platters, plates, and dishes, decanter-stands, bottles, jars, flasks, and various articles of use and ornament, mostly prepared by pressing in moulds. Picture-

frames, looking-glass frames, brackets for statuettes and lamps, ornamental mouldings for rooms, ornamental flower-pots and stands, are among other applications of gutta-percha; while a most miscellaneous assemblage of cricket-balls, bouncing-balls, golf-balls, fencing-sticks, police-staves, portmanteaus, book-backs, portfolios, embossed globes and maps for the blind, official seals, envelope-boxes, powder-flasks, box-lids, skates, ice-sledges, linings for damp walls, funnels, stoppings for hollow teeth—all these show into how many branches of domestic employment and amusement the use of gutta-percha now enters. Many articles of ornamental character have singular beauty of surface imparted to them by very simple means; different pieces of gutta-percha have slight differences in colour, and when two or more are pressed into one mould, the varying shades of colour give rise to a grained or clouded appearance, which becomes singularly rich when the surface is varnished.

8. The out-door and manufacturing purposes to which this remarkable substance is applied, are, if not more varied, certainly more extensive than those of a personal or domestic character. This might naturally be expected, from the power possessed by gutta-percha of resisting the action of liquids. Gutta-percha pipes are used to a large extent for the conveyance of water. They are employed in some of the water-works in different parts of the kingdom. In connexion with the celebrated Croton Aqueduct, at New York, there is a gutta-percha water-pipe nearly a thousand feet in length, laid along the bed of a river, and kept down by numerous small anchors. They are sometimes substituted for leaden pipes, in connexion with cisterns and water-butts, on account of the power possessed by gutta-percha of resisting the action of frost. They are recommended by many physicians for general use instead of lead, as obviating the possibility of forming poisonous salts of lead by the action of impure water. They are sometimes used as suction-pipes for fire-engines, and as hose

for applying the water of a street plug to the extinguishing of fires. They have been found valuable in watering gardens, in sprinkling streets, and in wetting malt in the malt-kilns. They have been used as syphons for drawing water from some of the Welsh collieries. They are adopted by the captains of some ships for conveying water up from the tanks or casks in the hold. They are used both as suction-pipes and delivery-hose in many kinds of pumps and engines; and the same waterproof quality which constitutes one of the excellencies of gutta-percha as a material for water-pipes (its elasticity being another), also renders it suitable as a lining for cisterns, and as a material for vessels intended to hold water.

9. But gutta-percha pipes can convey other liquids besides water; they will serve for the conveyance of acid chemical liquids which would corrode metal pipes, and vessels for containing such liquids, as well as pipes for conveying them, may with equal advantage be made in this singular material. Hence many manufacturing chemists employ gutta-percha pipes for transmitting powerful acids from vessel to vessel; for lining the vessels and spouts and funnels employed in connexion with such acids, and for lining carboys in which acids are sent to other manufacturers. Liquid manure, which contains powerful alkaline and acid substances, has a tendency to corrode metal pipes, and agriculturists have found advantage in employing gutta-percha pipes to distribute the liquid manure over their fields; and as this material resists the action of liquids, so will it likewise oppose resistance to the corroding action of gases. Advantage has been taken of this fact to furnish gas-lighting apparatus with gutta-percha tubes. Such a tube, two or three feet in length, with a gas-pipe at one end and a gas-burner at the other, furnishes a very useful portable gas apparatus, susceptible of removal from one part to another of a room, warehouse, or workshop.

10. Useful as gutta-percha tubes may be in the con-

veyance of water, chemicals, and gas, they are still more remarkable, perhaps, in respect to the conveyance of sound. No other known substance conveys sound with so little diminution of intensity; and hence a gutta-percha pipe has superseded most other kinds of speaking-tubes. Manufacturers who have extensive buildings now speak through gutta-percha tubes to convey messages from one department to another. Merchants transmit orders from the counting-house to the shop or warehouse by similar means, and the apparatus is the more approved, that a whisper is audible enough for the purpose in view; indeed it is asserted that words can be heard through a tube, a hundred feet in length, better than if spoken in the same tone in an open room by one person to another a yard or two distant. Conversation-tubes are sometimes used in railway-carriages, where the noise, under ordinary circumstances, almost puts a stop to conversation. A few of the better-conducted omnibuses have speaking-tubes laid along the top, to communicate between the driver and the conductor; or in the interior, to communicate between the passengers and the conductor. Gutta-percha hearing-tubes are used in some churches for the benefit of those whose hearing may be defective. In such cases a gutta-percha funnel or trumpet is fixed to some part of the pulpit, near the head of the minister; a tube is carried down from this funnel, under the floor of the church, and into the pew where its services are required. One very remarkable and useful result of this system is, that the tube under the floor may be regarded as a kind of main-pipe, through which *sound may be laid on*, and conveyed to as many persons as need be, by short branch tubes. A hearing-tube of this kind was laid down in Exeter Hall a few years ago. Medical men have had gutta-percha speaking-tubes fixed from their street-doors to their bedsides, whereby a message concerning a sick patient may be conveyed to them in the night while they are yet in bed. Some of the coal-mines have speaking-tubes many hundred feet in length, for

the purpose of maintaining communication between the top and the bottom. Small apparatus for the hand or the table have been contrived for domestic use, to facilitate conversation between persons of whom one is defective in hearing; speaking-trumpets, ear-trumpets, ear-cornets, and sound-receivers, of many different forms, are made in gutta-percha for this purpose.

11. Besides pipes for conveying water, chemical liquids, sewage-manure, gas, and sound, gutta-percha is now employed in the manufacture of a vast number of articles useful in engineering and the industrial arts. In some cases the elasticity, in others the water-resisting property, are brought into requisition, while it not unfrequently occurs that both kinds of services are required at the same time. Pump-buckets, valves, and clocks are now frequently made of gutta-percha. They require no seams, and they are unaffected by cold water, for both which reasons their inventors claim for them a superiority over leather buckets and valves. An entire pump of gutta-percha has been made for pumping up liquid-manure, the pipe, piston, and valves being quite unaffected by the acids in the liquid. The breasts of water-wheels are now occasionally covered with gutta-percha instead of leather. In weaving woollen cloths water drips from the weft-threads, and tends to soften and injure the leather with which the shuttle-bed is covered: this is sometimes obviated by employing gutta-percha instead of leather. On shipboard this substance, from its waterproof quality, its lightness, its toughness, its easy modification of shape when warm, and its power of resisting the action of sea-water, renders many valuable services. It is made into buckets, speaking-trumpets, fishing-net floats, ship-sheathing waterproof canvas, air-tight life-boat cells, hold-water pump-tubes, round and twisted cords, lining for boxes, tiller-ropes, flasks and bottles, bowls and basins, chart-cases, life-buoys, and many other articles serviceable to seafaring men. In engineering matters gutta-percha is now frequently employed for packing and washers in

mill-work, for feed-pipes in locomotive engines, and for other parts of working machinery. It is also occasionally employed as felt-edging for paper-making. Bosses and flax-holders, used in the flax manufacture, have lately been made of gutta-percha. Gutta-percha boats have been found useful by our Arctic explorers. Captain Forsyth, while commanding one of the ships in search of the gallant Sir John Franklin, employed a gutta-percha boat, which remained uninjured while wooden boats were knocked to pieces by the ice: the explorers very properly gave the name of "Gutta-percha Inlet" to a creek or small bay which they examined by means of this gutta-percha boat. Builders sometimes employ gutta-percha, in blocks or sheets, as plugs, inserted while warm into stone or wood-work, for securing linings, frames, skirtings, casings, dados, panellings, and other parts of house construction. Manufacturers who use gunpowder have found that gutta-percha canisters preserve the powder from damp most effectually, and have employed them for this purpose. Millwrights and engineers now employ gutta-percha bands very extensively, to communicate motion from one wheel or shaft to another; the elasticity and toughness of the material render it very valuable for this purpose, and hence gutta-percha driving-bands are now to be seen connected with the steam-engines and machinery of breweries, distilleries, bleach and dye-works, print-works, cotton-mills, woollen-mills, iron-works, corn-mills, machine-works, brick-yards, paper-mills, ship-yards, saw-mills, and other large manufacturing establishments.

12. A very pretty mode has been introduced of making gutta-percha available in fine-art productions. A wood-cut engraving is prepared in the ordinary way; a thin piece of soft warm gutta-percha is carefully pressed down upon it, so as to produce a mould or reverse of the engraving; a cast from this mould is obtained upon the surface of a cylinder of gutta-percha, by rolling the cylinder over the cast, and printing is effected on

paper from this cylinder. Ordinary type, or type combined with a wood-engraving, may be printed from in the same remarkable way, and impressions of considerable delicacy have been produced by these means.

13. Perhaps one of the most popularly interesting modes of employing gutta-percha is as a covering for electro-telegraphic wires. The wonderful results produced give an interest to all the working details. A copper wire will convey an electric impulse to an immense distance; but in order that it may do so, some means must be adopted to prevent the lateral dispersion of the electric power. Gutta-percha has been found more effective than any other substance in insuring this insulation when it forms a closely-fitting envelope to the wire. When the Gutta-Percha Company had made their first submarine telegraphic wire, they subjected it to a remarkable experiment at their works in the City-road. The copper wire was coated with gutta-percha to the thickness of a black-lead pencil or a tobacco-pipe; about seventy miles of this coated wire were coiled in a barge; the wire was connected at one end with a galvanic battery, and at the other with a cartridge. The battery was put in action, and the cartridge exploded instantly, the shock having passed through the whole length of wire without forcing an exit laterally through the thin layer of gutta-percha. The coated wires for submarine telegraphs now render one of the highest services which art has ever presented to society. It was about fourteen years ago, viz., 1844, that attention began to be directed to the possibility of conducting telegraphic wires under water, by coating them with some non-conductor of electricity. The Admiralty caused an experiment to be made, a year or two afterwards, across the mouth of the harbour from Portsmouth to Gosport. This perfectly succeeded, and led gradually to the formation of Submarine Telegraph Companies. In August, 1850, a telegraphic wire was sunk in the Channel, from England to France; there were thirty miles of copper wire, enclosed in gutta-percha to a thickness of

half an inch. The wire was carried across, but it proved to be too weak; it snapped in twain. The Company then re-commenced operations on a larger scale. In September, 1851, they succeeded in laying down a telegraphic cable of large size; the cable contained four wires, each coated with gutta-percha. A coating of the same substance encircled them all collectively; a sheathing of yarn, steeped in tar and tallow, was applied exterior to the gutta-percha, and outside the whole was a twisted spiral of ten galvanized iron wires. The cable, which was more than an inch in thickness, 24 miles long, and 180 tons in weight, was successfully carried across the Channel from the South Foreland to the French coast, at Sangatte, and telegraphic communication immediately commenced. In May, 1852, a telegraphic cable, 65 miles long, but of small diameter, was carried across the Irish Channel from Holyhead to Dublin. In October, 1852, the submarine telegraph from England to France was placed in connexion with a subway telegraph (under the coach road) from London to Dover. In May, 1853, a submarine telegraphic cable, containing six wires, insulated in gutta-percha, was carried across the Irish Sea, from Portpatrick, in Scotland, to Donaghadee, in Ireland. In June, 1853, submarine telegraphic communication was established between England and Holland, by sinking a telegrapic cable, 119 miles in length, from Orfordness in Suffolk, to Scheveningen, near the Hague. About the same period a submarine cable was carried across from St. Margaret's, near the South Foreland, to Middlekerke, near Ostend, in Belgium; the cable was 70 miles in length, and was of so great diameter, that it weighed 600 tons.

This is perhaps the crowning triumph of gutta-percha, so far as practical applications have yet gone, but we may with full confidence anticipate still more varied uses of a substance possessing so many curious and valuable properties.

GEORGE DODD.

Natural Philosophy.

HEAT.

BY JOHN TYNDALL.

LESSON I.

MEASUREMENT, ETC.

1. On the measurement of heat.— The sense of touch is our first thermometer. If I lay hold of a hot body it produces a certain change in my hand; the intelligence of this change runs up along the sensor nerves to the brain, and the feeling experienced furnishes a rough estimate of the temperature of the body. Similarly, if I place my hand upon a lump of ice, I am conscious of cold. But these sensations or feelings cannot be expressed by *numbers*, and this numerical estimate of temperature is what we at present require. The senses, in fact, may wholly deceive us. If I come into a room, and lay my hand in succession upon the metal, wood, and cloth which it contains, I experience three different sensations. When the air of the room is hot, the cloth feels warm, the wood warmer, and the metal warmest of all. If the air of the room be cold, the series is reversed, and the metal becomes coldest of all. But all these substances, while they affect the senses thus differently, have, in reality, one and the same temperature, namely, that of the air in the room. Two persons have been known to meet on a mountain, the one ascending and the other descending; the descending traveller casts his cloak from him, complaining of its warmth, while the ascending traveller draws his cloak more closely about him, and complains of cold. The fact is, our bodies are perpetually changing within certain limits. We have winter bodies and summer bodies; and a day which we should consider warm in winter would be bitterly cold

in summer. It is manifest that no certain science could be founded on the indications of an instrument so varying as the sense of touch. What then are we to do? Heat has been called a fluid; but we cannot measure this fluid by the quart—indeed we cannot measure heat directly at all; but we can measure with great accuracy the effects which heat is capable of producing, and these effects furnish us with an estimate of its quantity.

2. Whenever we speak of "quantity" in science, a certain fixed standard is always implied. Let me briefly indicate how this standard is obtained in the case of heat. The ordinary thermometer consists of a glass tube with a fine bore, which is blown out into a bulb or a cylinder at one end. The bulb and tube are partially filled with mercury. Now, one of the commonest effects produced by heat is that the addition of it causes bodies to expand, while the abstraction of it causes them to contract. Let our glass bulb and stem be surrounded by melting ice at the level of the sea, say on the coast of England; the mercury contracts as it becomes colder, the column in the glass tube sinks, and finally, when the mercury has assumed the temperature of the melting ice, the column will become stationary. You may now sail away from England to the North Pole and make the experiment there; to the Torrid Zone and try the experiment there. You will always find that the mercury, surrounded by the *melting* ice, stands at precisely the same point all the world over. It is not that the mercurial column cannot be caused to sink lower. For if the ice be suffered to fall below the exact temperature *at which it melts*, the thermometric column sinks immediately. Its constancy when placed in the melting ice is simply due to the fact that ice melts, or that water commences to freeze, at precisely the same temperature in all parts of the world.

3. Let the point at which the mercury stands be carefully marked—it is the *freezing point* of the thermometer. Let the same instrument be immersed in boiling water at the sea level on the English coast—the mercury expands and rises in the tube, until it attains the tempe-

rature of the boiling water. Here it remains stationary. Let the point at which it stands be marked—this is the *boiling point* of the thermometer. You may now repeat the experiment as before: travel north or south as you may; so long as you keep at the level of the sea, or, more accurately, so long as the height of your barometric column remains constant, the height at which the mercury stands in the thermometer plunged in boiling water will be perfectly constant also. The distance between the freezing point and boiling point is divided into a certain number of equal parts called degrees, which are sometimes marked upon the glass tube itself, and sometimes on a scale attached to the instrument.

4. The possession of these two fixed points enables us to compare one thermometer with another. It is manifest that the length to which the thermometric column expands between the freezing and the boiling temperature must depend upon the size of the bulb and the bore of the thermometer tube. If the bulb be large and the bore fine, the length through which the column expands will be greater than if the bulb be small and the bore wide. Thus the degrees of different thermometers may have *different lengths;* but they are of equal values. If in two thermometers the distance between the boiling point and the freezing point be divided into the same number of equal parts, it is plain that the body which shows 10° or 50° of temperature with one thermometer will show 10° or 50° with the other.

5. On the thermometer of Fahrenheit, which is the one mostly used in this country, the distance between the freezing point and boiling point is divided into 180 equal parts. Fahrenheit dipped his thermometer into a mixture of snow and salt, and found that the mercury fell much below the freezing point of water. He unwisely concluded that the temperature of the snow and salt was the lowest attainable; and hence he was induced to mark that temperature 0 upon his thermometer: starting from this, he found that the freezing point of water was 32 of his degrees higher in tempera-

ture; and on his thermometer accordingly the freezing point is marked 32°. This number, added to 180°, gives 212° as the boiling point of water, according to Fahrenheit's scale.

On the thermometer of Celsius, which is that most commonly used in France, the freezing point of water is called 0, and the distance between the freezing point and boiling point is divided into 100 equal parts. It is therefore usually called the Centigrade thermometer.

The thermometer of Reaumur is very commonly used in Germany, and on it the distance between the freezing and boiling points is divided into 80 equal parts.

6. Hence we see that 180° of Fahrenheit equal 100° of Celsius, and 80° of Reaumur; or 9° of Fahrenheit equal 5° of Celsius, and 4° of Reaumur. From this proportion it is easy to convert the degrees of one scale into those of another, but this variety of division is nevertheless a perpetual source of inconvenience. When a scientific man is intent upon his work, he does not wish to have his attention distracted by having to translate the language of one thermometer into that of another. Besides, the term degree is sometimes used without mention of the scale to which it belongs, and thus uncertainty and error are introduced. But nations are inert, and alter their habits with reluctance. To cope with this inertia a corresponding energy, the energy of youth, is required. Is it too much to hope that some of my readers may at a future day lend a hand in removing the inconvenience attendant on the use of three different thermometric scales?

7. On the boiling point of liquids.—Let us here endeavour to comprehend clearly the circumstances under which a liquid boils. Look, for example, at a vessel of boiling water: the water by heat is converted into steam, which rises in bubbles to the surface; and sometimes, where the action is not too violent, you may see one or more of these bubbles floating on the surface for a considerable time. Just consider the state of the film of water which constitutes such a bubble. It has

steam within it and air without it. Supposing the bubble to possess a surface of one square inch, we know, from a preceding article, that the atmosphere presses upon its surface with a force of 15 lbs. How is it then that the fragile thing is not crushed by this immense pressure? simply because the pressure of the steam within is exactly equal to that of the air without. The film is in fact enclosed between two elastic cushions which press upon it equally in opposite directions; and this explains an expression that you will often meet with, namely, that the pressure of steam at 212° Fahr. is equal to that of one atmosphere. But you may retort by saying that if the bubble thus depends upon the pressure of the atmosphere upon it, the boiling point of a liquid must vary as the atmospheric pressure varies. Take for example the case of a bubble floating on a vessel of boiling water at the summit of Mont Blanc; the pressure of the steam within such a bubble is also equal to the pressure of the air without it. But the pressure of the air must be far less than at the level of the sea, as we have here a great part of the atmosphere below us, and hence the steam within the bubble cannot have the same elastic force as when the water is boiled at the sea level. This reasoning would be in exact accordance with facts. The steam above *has* less elastic force than the steam below, and to produce this feebly-elastic steam less heat is required; or, in other words, the boiling point on the mountain is lower than at the level of the sea. On Donkia mountain in the Himalaya, at an elevation of 18,000 feet above the sea, water boils at a temperature of 180° Fahr. At the Hospice of St. Gothard, which is nearly 7,000 feet above the sea, the boiling point is 199°. At Berlin, which is very low, being only 131 feet above the sea, the boiling point is 211·6° or nearly 212°. I have said in another place that the heights of mountains are ascertained by means of the barometer. Precisely the same information may be obtained by means of a thermometer, on account of the gradual lowering

of the boiling point as we ascend above the level of the sea.

8. People who take chocolate for breakfast can tell when the servant has omitted to make the water boil; for if the water be not boiling, or nearly so, the chocolate will not swell. Were such people transported to Donkia mountain they must be content with an inferior beverage, for there the heat of boiling water would be insufficient to make good chocolate. Tea, soup, starch, all of which require a temperature near 212°, must be very inferior when made at such a height.

9. But it is not necessary to ascend a mountain in order to see the dependence of the boiling point upon atmospheric pressure. If a vessel of hot water be placed under the receiver of an air-pump, on exhausting the receiver, and thus removing the pressure from the surface, the water will boil. In the case of the more volatile liquids, it is not necessary to heat them at all. For example, alcohol at an ordinary temperature will boil violently when the atmospheric pressure is removed by the air-pump. Let the neck of a flask half filled with water be furnished with a stop-cock, and let the water in the flask be boiled over a lamp. The cock being open, the steam generated will escape and carry with it the air which occupied the upper portion of the flask. When all the air has been removed, and the space is filled with pure steam, let the stop-cock be closed, and the flask removed from the lamp. Ebullition ceases. But if a little cold water be poured upon the upper part of the flask, the cooled glass partially condenses the steam within, relieves the water of its pressure, and the liquid again boils. The whole flask may be plunged into a vessel of cold water, and a violent ebullition thus produced.

10. I think you are now prepared to accompany me in the examination of a wonderful phenomenon, which illustrates in a striking manner the principle which we have been considering. I allude to the Geysers of Iceland. Let us approach the subject calmly, make our-

selves clearly acquainted with the facts, and proceed like philosophers to the explanation. The Great Geyser of Iceland consists of a tube 70 feet in depth and 10 feet in width, which expands at the top into a basin between 50 and 60 feet in diameter. The tube and basin are lined with a smooth plaster deposited by the water, and which is so hard that it resists the blows of a hammer. On arriving at the Geyser we will suppose a traveller to find the tube and basin full of hot water. Explosions which shake the ground are heard at intervals beneath the earth, and after these explosions the water in the basin is agitated. The Geyser column is lifted up, producing an eminence in the centre of the basin and causing it to overflow. These liftings of the column may be regarded as so many unsuccessful attempts at an eruption. In time, however, the water in the tube becomes hotter, the explosions and the agitation of the water in the basin become more frequent, the eminence in the centre of the basin rises higher than before, and finally the hot liquid wrapped in clouds of steam, is projected upwards to a height which sometimes exceeds 150 feet.

11. Sir George Mackenzie, who travelled in Iceland, and has written a description of the island, attempted to explain this phenomenon, and his theory met with general acceptance for many years. He assumed the existence of a subterranean cavern half filled with hot water, and communicating by a bent canal with the tube of the Geyser. The upper portion of this cavern he imagined to be filled with steam, and at certain intervals he supposed the water in the cavern to be suddenly heated, and steam of great force to be generated, which, reacting upon the surface of the water in the cavern, pressed it downwards and the Geyser column upwards. I mention the theory thus on account of the hold which it long retained upon men's minds. I will not dwell upon it further, but will proceed at once to the true explanation given by Professor Bunsen of Heidelberg, who visited Iceland in the year 1846.

12. In natural philosophy we must be able to guess and speculate, but the true philosopher will check his speculations whenever it is possible by an appeal to facts. Bunsen did so in his examination of the Geyser. By the immersion of suitable thermometers he made himself accurately acquainted with the temperature of the water in the tube, and found that the heat increased gradually from the top to the bottom. He ascertained the temperature at 23 hours 13 minutes, at 5 hours 31 minutes, and at 10 minutes, before a great eruption. He found that as the time of an eruption drew near, the water in the tube became hotter; but what is most remarkable, he also found that even immediately before the eruption took place, at no portion of the tube had the water attained its boiling point, that is to say, the boiling point corresponding to the pressure upon it. I hope you will understand me here. The water in the basin had merely the pressure of the air upon it, and its temperature was considerably under 212°. The water at the bottom of the tube was, it is true, considerably above 212°, but as it had here to bear the pressure, not only of the atmosphere, but also that of a column of water 70 feet high, its temperature was actually several degrees lower than that at which the liquid could boil under such a pressure.

13. But if the entire column of water be at a temperature below its boiling point, how is the ebullition in the basin to be accounted for? How are those liftings of the column, which I have called unsuccessful attempts at an eruption, to be explained? The Geyser-tube is fed by ducts which ramify through the hot rocks, and it is the steam suddenly generated in these ducts, and rushing into the tube at intervals, which lifts the column and produces the explosions. I have now to draw your attention to another very remarkable fact, and I hope if my facts come too thick that you will pause and reflect, and thus give yourself time to comprehend them clearly. Bunsen found that at a height of 30 feet from the bottom, the water approached nearer to its

boiling point than at any other portion of the tube. The actual temperature here was 252°, which was within 3° of the temperature at which the water would boil. This near approach to the boiling point can only be referred to the heat communicated to the column of water at this place by the sides of the tube.

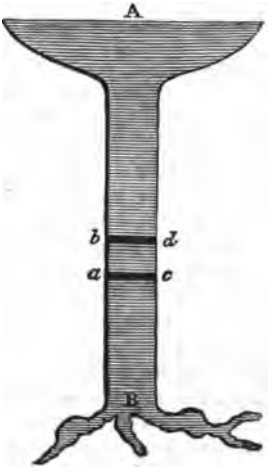


Fig. 1.

14. Thus furnished with the facts, let us now try to explain how, under such circumstances, an eruption is possible. Let A B fig. 1, be the Geyser-tube and basin, and *a c* a stratum of the liquid at 30 feet from the bottom. The temperature of *a c* just before an eruption is 252°. Suppose that by the entrance of a quantity of steam from the ducts which feed the tube, the column is lifted so as to bring *a c* up to *b d*, 6 feet higher than its former level. This supposition, be it remembered, is quite in accordance with fact, for the eminences in the basin already referred to, show that the column is sometimes lifted more than 6 feet. When *a c* is lifted to *b d*, the stratum at *b d* has 6 feet less pressure upon it than before. Under this diminished pressure its temperature is *above its boiling point*. It possesses 252° but it would boil in its new position at 250°. What is the consequence? The excess of heat is instantly applied to the generation of more steam; the column is lifted higher, and the water below *b d* is relieved of its pressure; more steam is thus generated, which in its turn diminishes the pressure. Thus relieved, the mass of water in the lower portion of the

tube bursts into ebullition, propels the liquid above it into the atmosphere; and the Geyser eruption takes place in all its grandeur.

15. The more you ponder upon this explanation, the more, I think, you will be satisfied with its beauty and sufficiency. But when a test of a theory can be applied, let us not neglect to apply it. It will be observed that the great difference between the theory of Bunsen and that of Mackenzie is, that Bunsen rejects the cavern, and finds in the tube itself a sufficient cause for the phenomenon: can we not test this by experiment? We can. I possess a tube of galvanised iron 6 feet long, and about 6 inches in diameter at its bottom. To increase the effect, and lessen the quantity of water, the tube tapers gradually towards the top; here it enters water-tight through the bottom of a basin of sheet zinc about 5 feet in diameter. The tube is filled with water; a fire is lighted beneath it, and at about 2 feet above the bottom, the tube is embraced by a second small fire, to imitate the lateral heating of the pipe of the Geyser. With this simple apparatus all the phenomena of the famous Iceland spring can be imitated to perfection. One experiment often made with this apparatus is very striking, and further illustrates the principle at present under consideration. The top of the tube is stopped with a cork; the water thus confined does not boil at 212°, but goes on heating until its vapour is sufficiently strong to force out the cork. Its excess of heat is then instantly applied to the generation of steam, and the consequence is, that the water is projected upwards to a height of 30 feet. This is an exact imitation of the action of a second spring in Iceland, which is called the Strokkur. The natives throw clods into its tube and choke it up; after a little time these are ejected like the cork, and the water of the spring is projected to a height surpassing even that attained by the Great Geyser.

LESSON II.

LATENT AND SPECIFIC HEAT.

1. ON LATENT HEAT.—Many of the terms of science are indicative of the theoretic views of those who first used them. Thus the man who first employed the term at the head of this section imagined heat to be something which could hide itself, in some way or another, in the pores of matter, so as to elude ordinary methods of observation. Latent heat always comes into play when a body changes its state of aggregation; when it passes from the solid to the liquid, or from the liquid to the vaporous or gaseous condition. While the case of water is still fresh in our minds, let us take it for an example. Suppose a lamp which burns with a perfectly constant flame, and which always gives out the same quantity of heat per minute, to be placed under a vessel containing water at 32° Fahr., that is, just at the freezing point, and a thermometer to be placed in the water; as heat is communicated to the latter, the mercury will rise, until the point 212° is attained. Here the water will commence to boil, *and here the thermometer will cease to rise.* You may continue to apply heat, the lamp may be just as active as before, and communicate its due amount of heat per minute to the vessel, yet higher than 212° the water will not rise. If you immerse your thermometer in the steam which issues from the vessel, it also will show a temperature of 212°, and no higher, so that though the heat is given, it does not show itself anywhere; it has hidden itself in the steam, or, to use the language of the discoverer of the fact, it has become *latent.* Let us now seek to be accurate in our observations, and endeavour to find the quantity of heat which is disposed of in this way. Let us suppose the experiment again commenced, and the time required by the lamp to heat a single ounce of water from 32° to 212°, or through 180°, to be accurately noted. Let the action now be continued until all the water has

been reduced to a state of vapour; it will be found that the time necessary to produce complete evaporation is almost exactly 5½ times the time required to raise the water through 180°. Hence, if the water had not boiled, but had gone on heating after it had reached 212° as before, it would, in the time necessary to reduce it all to vapour, have augmented its temperature by 5½ times 180°, or 990°. These 990° have been rendered latent by the steam, and this number is called the *latent heat of steam*. Added to the 212° which the water already possessed, it would give 1202° for the total temperature of such water; but instead of reaching this, it is cut short at 212°, and all beyond this point is hidden in the vapour.

2. Let us now reverse the experiment and see whether we cannot bring this heat from its hiding place. Let A, fig. 2, be a flask containing water, and through its cork let one end of a glass tube C pass air-tight. Let the other end of the tube dip into water at 32° contained in the vessel B. Heat being applied to the flask A until the water boils, the steam will issue through C, and be condensed by the water in B. By degrees, the water in B becomes heated, and it finally boils. We will now endeavour from this experiment to determine the latent heat of the steam, and thus check the result which we have already obtained. Suppose the vessel B at the commencement of the experiment to have contained 5½ ounces of water, it will be found at the moment when it commences to boil to contain 6½ ounces; that is to say, 1 ounce of water in the shape of steam has gone over from A; that steam had a

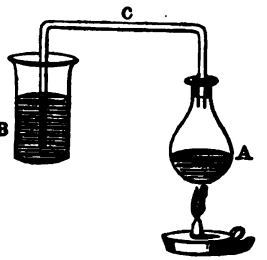


Fig. 2.

temperature of 212°, the water which it boils has a temperature of 212°, consequently the ounce of steam has boiled the 5½ ounces of water *without losing any sensible temperature of its own.* It has boiled the water by its latent heat.

3. Now, suppose that a man with 100 shillings in his purse distributes these equally among five persons, each person would receive 20 shillings; if instead of thus dividing his money he gave it all to a single individual, this person would, of course, possess five times as much as any one of the five would have done. So also if the ounce of steam, instead of distributing its heat among 5½ ounces of water, had given it all to one ounce, that ounce would have received 5½ times the number of degrees of the larger mass; and as the number of degrees received by the larger mass is 180 , a single ounce would receive 5½ times 180°, or 990°. Thus, in our first experiment we found that one ounce of water on being reduced to steam, hid 990° of heat; and in our second experiment, we have brought this heat from its hiding-place, and found that it would be exactly capable of heating an ounce of water (supposing it not to boil), 990°. One result, therefore, confirms the other. I may remark, however, that recent experiments make the latent heat of steam 967° instead of 990°.

4. The enormous absorption of heat which accompanies the conversion of a liquid into vapour explains many singular phenomena. If you place a drop of ether upon the back of your hand, the liquid, being very volatile, speedily evaporates: heat is absorbed from the hand, and a sensation of cold is produced. The wine-coolers of the East consist of vessels of porous earthenware. A bottle of wine is placed within the cooler, and the space between the two is filled with water. This oozes through the porous cooler, and moistens the outside of it. The moisture is evaporated, and its place continually supplied with water from behind. Through this continued production of vapour a great amount of heat is abstracted from the water; the latter becomes cooled, and

produces the desired effect upon the wine. If the porous vessel be placed in a current of air, evaporation is hastened, and the cooling is more speedily effected.

5. Again; a stone in Lapland, and a stone on the burning plains of Sahara, have very different temperatures; but a traveller in Lapland has almost exactly the same temperature as a traveller in Sahara. The health of the human body appears to require that its temperature should only vary within very narrow limits, no matter where upon the earth's surface it may be placed. How does nature secure this constancy amid such varied external conditions? The evaporation from the body is the regulator. In hot countries this is greater than in cold, and thus the excess of heat is carried away.

6. Let a watch-glass containing ether be placed upon a small dish with a little water between the glass and dish, and let the whole be placed under the receiver of an air-pump: by working the pump evaporation is promoted, and in this way cold may be produced sufficient to freeze the watch-glass to the dish on which it rests. The experiment is most easily made with two watch-glasses which have their bottoms roughened by grinding. Turn one upside down, place a drop of water upon it, and on this place the second glass containing the ether. A very few strokes of the pump will be sufficient to freeze the glasses together. Care must be taken not to allow any portion of the ether to mix with the drop of water to be frozen, as this, on account of the difficulty of freezing the ether, would completely vitiate the experiment.

7. The cold produced by evaporation is strikingly exhibited by the instrument called the cryophorus. This instrument consists of two bulbs, A and B (fig. 3) united by a glass tube. A portion of water is introduced through an aperture at C, and is boiled until all the air is expelled through C, when the aperture is sealed with a blowpipe. The instrument is now complete. To show its action, let all the water be brought into one of the bulbs, say A, and let the empty bulb B be surrounded by a

freezing mixture. The water in A evaporates and makes its way to B, where it is condensed, thus leaving

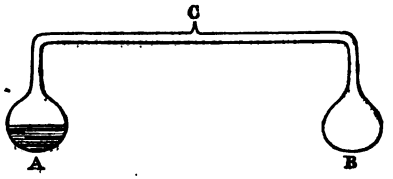


Fig. 3.

room for the formation of more vapour. Heat is thus continually abstracted from the water in A, which, after a short time, is converted into a mass of solid ice.

8. But perhaps the most remarkable case of refrigeration is that furnished by carbonic acid. At ordinary temperatures this substance is a gas: it is exhaled from the lungs, it effervesces from champagne and soda-water, and if an acid be poured upon chalk or marble, the gas is liberated in great abundance. By mechanical pressure this gas can be made to assume the liquid condition, and in this state it is preserved in iron bottles of great strength. When the cock of a bottle, filled with this liquid, is turned so as to open a communication with the air, a portion of the substance flashes suddenly into vapour, but not all. So great is the cold produced by the vaporization that a portion is actually frozen, and the solid carbonic acid may be collected as a pure white snow.

9. It is now necessary to say a word regarding the heat absorbed when a body passes from the solid to the liquid condition. Let us take ice as an example. Supposing we take the substance in midwinter, at a temperature lower than the freezing point—say at 15° Fahr., and place it in a vessel with a constant flame underneath it. A thermometer placed in the vessel will first show an increase of temperature; the mercury will rise

until it reaches 32°; at this point the ice will commence to melt, and at this point also the upward motion of the mercury will be arrested. As long as the ice continues melting, the thermometer will show a constant temperature of 32°, and when the ice has disappeared, but not before, the mercury will resume its upward motion.

It is manifest that we have here an instance similar to that already described in the case of steam. During the melting of the ice, heat is continually communicated by the lamp, but it does not show itself upon the thermometer. It seems to be hidden in the water; to use the ordinary term, it is rendered latent.

10. How are we to estimate the quantity of heat thus absorbed? We may do it in this way:—Take a pound of ice at 32°, that is, just at its freezing point. Take a pound of water at a temperature of 175°. Mix these together; when the experiment is properly made, it is found that a pound of water at this temperature is just sufficient, and no more, to melt the pound of ice. When the melting is complete, the resulting liquid is at a temperature of 32°; consequently the ice, on being rendered liquid, has received $175° - 32° = 143°$ of heat, without becoming sensibly warmer. To the thermometer and to the hand it is of the same temperature before it is melted and after it is melted. The 143° of heat communicated to it have therefore been rendered latent. This number expresses the latent heat of water.

11. We may check this result by the following experiment:—Let two lamps which give out the same quantity of heat per minute be placed under two equal vessels, one of which contains a pound of ice at 32°, and the other a pound of water at the same temperature. Let a thermometer be placed in each vessel. That immersed in the water will rise from the commencement of the experiment; that immersed in the ice will remain stationary at 32° until all the ice has been melted. At the moment when the last bit of ice disappears let the thermometer, plunged in the water, be read off: it will

show 175°. Subtracting 32° from this, we have 143° as the quantity communicated to the water by the lamp; but the same quantity of heat has been communicated by the second lamp to its vessel without raising its temperature at all. It has been applied to liquefy the ice; hence, as before, we arrive at the conclusion that these 143° have been rendered latent during the liquefaction.

12. It is not difficult to show that water in freezing yields up the heat thus rendered latent; but the experiment is much more striking with sulphate of soda. Let as much of this salt as possible be dissolved in boiling water, and let the solution be placed in a flask or beaker to cool: if it be permitted to remain perfectly quiet, it will cool gradually, and remain, when cold, in a liquid condition. If a thermometer be now plunged into the solution, it immediately thickens to a solid round the thermometer, and the process of crystallization thus commenced speedily extends itself throughout the entire mass. At the same time the thermometer will be seen to rise, the latent heat of the liquid being rendered free by the passage of the substance to the solid state.

13. The dissolving of a little saltpetre in water instantly reduces its temperature, as may be seen by the falling of a thermometer plunged in the liquid. Air-thermometers, being more sensitive than mercurial ones, are the best for such experiments. Any boy may readily make an air-thermometer for himself. Let a common test-tube be taken and furnished with a well-fitting cork. Through this cork let a small glass tube pass air-tight, and let its lower end dip into a little coloured water (*b*, fig. 4) at the bottom of the test-tube. When the latter is immersed in a warm liquid, the air at *a* expands, presses upon the surface of the water, and forces it up

Fig. 4.

in the tube, *c*. Very small differences of temperature may be thus rendered manifest.

14. If space permitted I might show you the influence of the facts we have been considering upon the climates of various countries. Europe has a remarkably mild climate, considering its position upon the surface of the globe. The eastern coast of America has a climate far more severe than the opposite one of western Europe. The river Hudson, which is in nearly the latitude of Rome, is sometimes frozen during three months of the year. Nay, so great is the cold observed in some parts of North America, that it gave rise to the idea that the north pole of the earth was once in this region, and that through some great convulsion of Nature the axis of the earth had been shifted from the position which it once held. But this idea would scarcely have arisen had it been known how immovable the position of the earth's axis really is; and, besides this, our present progress in meteorology has quite explained the difficulties to which we refer. Compare the *western* coast of America with the western coast of Europe, and the differences of temperature disappear. The land between the Rocky Mountains and the Pacific Ocean has a European climate; the reason being that the vapours drifted towards the continent from the Pacific are condensed by the mountains; in condensing, they yield up their latent heat, and thus preserve the climate mild. It has been thought that the warmth of Europe was due to the descent of air which had passed over the hot soil of Africa; but this air, on account of the velocity imparted to it from west to east by the diurnal motion of the earth, does not reach Europe at all. The cradle of our southerly winds is the West Indies, and the secret of the mildness of Europe is, that it is the condenser of the vapour of the Caribbean Sea.

15. On specific heat.—In treating of latent heat I said that the term was suggestive of the theoretic opinions of the person who first used it. Heat, like

light, magnetism, and electricity, was ranked among what were called imponderable bodies—bodies without weight, but still capable of being mixed up with ordinary matter. Heat, looked at from this point of view, was called by the Germans "wärmestoff"—that is, the stuff or material of heat; and in chemical books we still find the combination of bodies with heat spoken of, just as such books speak of the combination of one material substance with another. This is called the material theory of heat. Now it is found that different bodies require very different amounts of heat to make them equally warm. Suppose, for example, all the heat given out by the combustion of an inch of candle to be communicated to a pound of water at a temperature of 32°; the water will have its temperature augmented a certain number of degrees. If the same amount of heat be imparted to a pound of mercury, the temperature of that liquid would be raised thereby far higher than that of the water. In fact, to raise a pound of water a certain number of degrees in temperature would require thirty times the heat necessary to raise a pound of mercury the same number of degrees. Hence, in accordance with the material theory of heat, it was supposed that water possessed a greater power than mercury of drinking in the heat. This power was called its *capacity for heat*, and sometimes its *specific heat*. We have referred to two liquid bodies; but solids also differ from each other in this respect. If the same absolute amount of heat be communicated to a pound of lead and a pound of iron, when examined by the thermometer the iron will be found to be much cooler than the lead; it would require a greater amount of heat to raise it to the same temperature. Hence iron is said to have a greater capacity for heat, or a greater specific heat, than lead has. If we immerse a pound of lead and a pound of iron in boiling water, the quantity of heat taken in by the iron in order to bring it up to the temperature of the boiling water will be greater than that taken in by the

lead. How can we prove this? Simply by plunging our lead and iron into two separate vessels containing the same amount of cold water. The water in contact with the iron will be much more heated than that in contact with the lead. Or if a ball of iron and a ball of lead, heated in the manner described, be placed upon a thin plate of stearine, the iron will melt its way through and fall to the ground while the lead remains sticking in the mass. Such experiments as these inform us in a general way that one substance has a higher specific heat than another; but they do not tell us how much the specific heat of one body exceeds that of another. To ascertain this, more accurate experiments must be resorted to. Perhaps the most celebrated experiments on this subject are those of Lavoisier and Laplace—the former a great chemist who suffered death by the guillotine during the first French Revolution; the second, a celebrated mathematician. In their experiments they made use of an instrument called a calorimeter, of which the following is a description :—

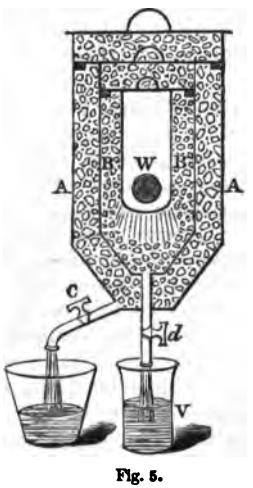


Fig. 5.

16. A (fig. 5) is a vessel of sheet metal; B is a second vessel of a similar shape, placed within the first. A cover being placed upon each of the vessels, A and B, there is a space between the two vessels all round. This space is filled with pounded ice, which, when the vessel is placed in an atmosphere above 32°, gradually melts, and the melted water is carried off by the cock C. Within B is a third vessel, and the space between it and B is also filled with pounded ice. Each vessel is furnished

with a cover, so that the ice can be placed all round, as shown in the figure. Within this third vessel, the warm body, W, whose specific heat is to be determined, is placed. Now let us understand the instrument: the outer jacket of pounded ice effectually protects the ice in the vessel B from the action of the atmosphere. The ice in B is thus preserved at 32°, and cannot be melted by the external air. Hence, whatever is melted in B must be wholly due to the heat yielded by the body, W. The liquid thus produced is carried off by the cock *d*, and received into the vessel, V.

17. The principle from which Lavoisier and Laplace started was, that the quantity of heat which a body contains will be measured by the quantity of ice which it is able to liquefy. If we place one pound of iron, heated up to the temperature of boiling water, in the apparatus, and permit it to cool down to 32°, and then subject our pound of lead to the same experiment, on weighing the amount of water produced by each, we should find them to be in the ratio of 11 to 3, that is to say, a pound of iron in falling through the same number of degrees yields nearly four times the quantity of heat yielded by an equal weight of lead.

18. The specific heat of a body accurately defined is the quantity of heat which the body requires to raise the unit of weight, say a pound of water, 1° in temperature. But the quantity of heat required to raise the temperature of a body 1° is the quantity which it loses in falling through 1°; and this latter is measured by the quantity of ice which it is able to liquefy.

Supposing a body at 42° to be placed in the calorimeter and permitted to sink to 32°, or through 10°; if the quantity of ice melted by the body be 10 grains, this would be a grain for every degree; or, more generally, if we divide the weight of melted ice by the number of degrees through which the body melting it has fallen, we obtain the quantity which the body would melt by falling through 1°. This quantity expresses the specific heat of the body.

19. In tables of specific heat the standard referred to is that of distilled water: its specific heat is set down as 1. The following table shows the specific heats of a few other well-known substances:—

Iron	0·11379
Zinc	0·09555
Copper	0·09515
Silver	0·05701
Lead	0·03140
Bismuth	0·03084
Platinum	0·03243
Gold	0·03244
Mercury	0·03322

We here see how greatly the specific heat of water predominates over those of all the other substances mentioned. The specific heat of water is nearly 10 times that of iron, 18 times that of silver, and is more than 30 times that of mercury. This is the place to remark how suitable its low specific heat renders mercury for thermometric purposes: it is promptly affected by changes of temperature, which it would not be if its specific heat were high.

Calling the specific heat of water 1, that of atmospheric air is 0·25, or just one-fourth part that of water. Hence a pound of water in losing 1° of heat would heat a pound of air 4°, or it would heat 4 pounds of air 1°.

But a pound of air fills about 770 times the space of a pound of water, and hence 4 pounds of air fill 3080 times the space of a pound of water. Therefore a pound of water by parting with 1° of temperature would be able to raise 3080 times its own bulk of air 1°.

20. The vast importance of this property of water as a regulator of climate at once suggests itself. No wonder that the climates of islands are so much milder and more equable than those of continents. The surrounding sea, thirsty, as it were, for the sunbeams, drinks them in, but nevertheless preserves itself comparatively cool, and thus tempers the island air. In winter the heat thus stored up is slowly given out; every gallon

of water on giving up its degree of heat, warming 3080 gallons of air by the same amount, and thus shielding the island from winter cold. We here see the explanation of the fact that the winter of Iceland is less severe than that of Milan. We can also explain why it is that with us laurels and other plants thrive in the open air, which are killed by the winters of more southern lands; while our summers refuse to ripen the grapes which those lands produce in abundance. Thus it is that the simplest facts which we learn in the laboratory constitute the stepping-stones by which the human mind attains to the accurate comprehension of the grandest phenomena of Nature.

LESSON III.

EXPANSION BY HEAT.

1. ON THE EXPANSION OF SOLIDS BY HEAT.—I have already stated that the expansion of mercury by heat is made use of as a measure of the heat which produces the expansion. All bodies, without exception, are affected in this way by heat, but all are not affected in the same degree. A rod of steel, for example, on being heated from 32° to 212°, expands $\frac{1}{91\frac{1}{2}}$th of its own length; whereas a rod of lead similarly heated expands $\frac{1}{35\frac{1}{2}}$th of its length: the expansion of lead by heat is, therefore, much greater than that of steel. Brass expands $\frac{1}{54\frac{1}{2}}$th of its length on being heated from 32° to 212°, whereas iron expands only $\frac{1}{81\frac{1}{7}}$th. Now suppose a bar of brass and a bar of iron to be closely riveted together, so as to form a single compound bar, as shown in

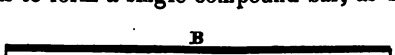


Fig. 6.

fig. 6. When such a bar is heated, what must be the

consequence? The brass B expands more than the iron I, and in order to give this difference of expansion room, the compound bar is bent into a curve, as in fig. 7, the brass bar forming the outside of the curve. If instead

Fig. 7.

of heating the straight compound bar we cool it, the brass contracts most, and the bar is bent in the opposite direction. For certain chemical experiments it is necessary to have a metallic wire fused into glass tubes; both glass and wire must of course be red hot when this fusing takes place; and if, in cooling, one of them contracted more than the other, the rupture of the junction between them would be inevitable. Now barometer glass expands, on being heated, from 32° to 212°, $\frac{1}{11\frac{1}{73}}$th of its own length. Were we to fuse a bit of gold wire into such glass, rupture would assuredly take place in cooling, for gold expands on being heated from the freezing to the boiling point of water $\frac{1}{\frac{1}{6}\frac{1}{5}}$th of its length. Fortunately, however, there is a metal, *platinum*, whose expansion is $\frac{1}{11\frac{1}{6}7}$ th of its length, or almost exactly equal to that of glass. This metal is therefore always used in the construction of the instruments to which I have referred.

2. In the construction of bridges and buildings where metal tubes or beams are introduced, and also in the laying down of railroads, care must always be taken to allow for the expansion due to variations of temperature, for the force with which a body expands under the influence of heat is almost irresistible, and might produce serious consequences if it were not permitted free play. There is on the line of rails between London and Manchester a greater length of iron by about 500 feet in summer than in winter; and to permit this ex-

pansion to take place, the rails, when they are laid, are not brought close up end to end. Iron cramps in masonry often work themselves loose on account of the inequality of the expansion between them and the stone. The tires of wheels are heated before they are put on; in cooling they contract, and draw the wood-work together with great force. Hot rivets act similarly. The force of contraction has also been made use of to set the walls of buildings erect. If I remember aright, the experiment was tried with the cathedral of Armagh. The walls of the building gradually leaned away from each other, and to draw them together bars of iron were placed across the cathedral, passed through the walls, and furnished with nuts at the ends which might be screwed tight to the walls. The bars were heated and expanded. The nuts at the ends were made tight, and then the metal was suffered to cool; during its contraction it drew the walls together with an irresistible pull; and by repeating the process the walls were finally set erect.

3. In connexion with this subject a very interesting fact has been recently observed. A sheet of lead which lay on the south side of the choir of Bristol cathedral was observed to have slipped bodily down the roof, through a space of 18 inches, in two years. You might imagine that this was simply due to the slope of the roof, but the slope was such that the lead would never have slid down it by its own weight. How then did the lead get down? The case is instructive, and I would therefore draw your attention to it.

4. Imagine such a sheet of lead, lying upon an inclined roof, exposed to the temperature of a sunny day. It expands. If it lay upon a horizontal surface it would be pushed out in all directions equally by the expansion, but as it lies upon a slope, it will slide with greater facility downwards than upwards. The upward movement is opposed by gravity, while the movement downward is assisted by gravity. If the position of the upper and lower edges were marked by chalk before

the expansion took place, the lower edge, for the reason just given, will extend further over its chalk mark than the upper. Now suppose the chill of night to act upon the lead; it will contract. But it is easier to pull the upper edge down than to pull the lower edge up. If the position of the upper and lower edges were marked with chalk, as in the former case, before the contraction, it would be found that after the contraction the upper edge had moved further from its mark than the lower one. By expansion, therefore, the lower edge is pushed downwards, and by contraction the upper edge is pulled after it. Thus the mass of lead creeps like a worm, and although the space passed over in a day would be nearly imperceptible, the progress is sure, and in two years amounted, as I have said, to 18 inches.

Fig. 8.

5. The time which a pendulum requires to accomplish an oscillation depends upon its length: a long pendulum oscillates more slowly than a short one. Hence a pendulum, acted upon by variable weather, vibrates sometimes quicker, sometimes slower, and consequently would give inaccurate results. Various means have been used to render the oscillation uniform. You will sometimes see a vessel of mercury suspended at the end of a pendulum. When the temperature of the day increases, both the pendulum rod and the mercury expand, but the former expands *downwards*, while the latter expands *upwards*, and by this opposition the centre of oscillation, as it is called, is preserved constant. The gridiron pendulum is also very common; its principle will be understood from fig. 8. S is the knife edge on which the pendulum is suspended. A B C D

is a rectangle composed of iron rods: through a hole in the cross piece C D the rod *p q* passes. E G is a cross piece capable of moving up and down; and attached to this cross piece are the two brass rods E F and G H, which also rest upon the cross piece C D. When the warmth of the day increases, the rods A C and B D expand, and also the central rod *p q*. All these tend to push the pendulum bob *q* farther from the point of suspension. But the brass rods E F and G H also expand, and their action is to lift the pendulum bob and cause it to approach nearer the point of suspension. In the construction of the pendulum it is so arranged that these opposing actions exactly balance each other, so that the pendulum is maintained at a constant length. In fact we know from experiment that the expansion of brass is to that of iron as $1\frac{1}{2}$ is to 1; hence if the length of iron to that of brass in the pendulum be in the same ratio, the expansions neutralize each other, and a perfect "compensating pendulum" is obtained.

6. It has already been shown that different solid bodies expand differently when heated; but in some cases the same solid body expands differently in different directions. It is easy to conceive that in crystalline bodies the atoms may be packed more closely together in some directions than in others, and hence we might expect that, when such a body expands under the influence of heat, the atoms would be pushed asunder with different forces in different directions. Experiment justifies this conjecture. When the crystal gypsum is heated, it changes its shape, which would not be the case if it expanded equally in all directions. The crystal Iceland spar, when heated, expands considerably in the direction of its axis, but, strange to say, in a direction at right angles to the axis it *contracts*. This contraction, however, is not sufficient to balance the expansion; and the final result is that the volume of the crystal is augmented. It is easy to conceive that when a crystalline body of which the component crystals are confusedly arranged is heated, the unequal expansion of its various

parts may produce rupture among them to a greater or less extent, and this is doubtless the cause of the snapping noise sometimes heard during the cooling of melted zinc or antimony, and sometimes even in the case of the bars of a grate.

7. ON THE EXPANSION OF LIQUIDS BY HEAT.—Liquids expand more than solids under the influence of

Fig. 9.

heat. Let a retort be filled with water as in fig. 9, and let the vessel be chosen with a neck so narrow that when it is filled and inclined as in the figure, the capillary attraction of the neck shall be sufficient to prevent the liquid from flowing out. A lamp being placed underneath the retort, the dropping of the water into the beaker, B, soon demonstrates the expansion of the liquid.

8. When a vessel containing water is placed upon a fire, the lower portion of the liquid expands, and becoming thereby lighter, it ascends, while the heavier liquid sinks to supply its place. This in its turn becomes heated, and rises, being replaced by cooler liquid as before; and thus the heat communicated to the bottom of the vessel is distributed through the liquid. By placing in the water cochineal, or some other opaque powder of nearly the same specific gravity as the water, the existence of these up-and-down currents may be demonstrated. Similar currents exist in the tube of the Great Geyser already described. When scraps of paper are cast into the centre of the basin, they are driven from the centre towards the edge, and thence sucked down-

wards. The tube has an ascending current along its centre, and a descending current along its sides.

9. Let us now reverse our conceptions, and consider the case of a sheet of water exposed to the chilling influence of a freezing atmosphere. The surface of the water in contact with the air is cooled; it contracts, becomes heavier, and sinks, while the lighter water from below rises to supply its place. In this way the warmth is drawn from the depths and given to the atmosphere. This process continues till the superficial layer is cooled down to 39° Fahr., and at this point the contraction of the water ceases. At 39° Fahr. water possesses the greatest density that it is capable of possessing, and as it sinks below this temperature, and approaches the freezing-point, it *expands*. Hence the water which is at the surface when the temperature 39° is attained, remains there; it does not sink, but continues to float like a layer of oil upon the heavier water. When it reaches 32° it freezes, and thus forms a solid lid of ice, which shuts down the warmer water. Beneath this lid the fish may dwell unharmed; whereas if it were otherwise, if the abstraction of heat continued until the entire mass were frozen, the fish would be crushed to death by the act of congelation. Does it not appear as if Nature, in arresting the contraction of water at 39°, had stepped aside from her wonted course in order to preserve her creatures! On this point I will not dwell, as, with our limited knowledge of the purpose which runs through Nature, we are very liable to make mistakes. The metal bismuth, on cooling from a state of fusion, behaves exactly like water, although in its case there are no fish to be protected.

10. In cooling from 39° to 32° the expansion of water is gradual; but in the act of congelation a sudden expansion takes place, and the ice which results is considerably lighter than the water from which it is produced. The force of this expansion is irresistible; it will burst the thickest bomb-shell. It is a common experiment to fill an iron bottle with water, screw it

close, and place it in a freezing mixture to congeal. The act of congelation is accompanied by the bursting of the bottle. Before filling a bottle for this experiment, it is well to boil the water and expel the air. The same experiment may be made with fused bismuth. I once filled an iron bottle with the melted metal, and closing it with a screw tap, permitted it to cool. The bottle was rent from neck to bottom by the expansion of the metal on solidifying.

11. ON THE EXPANSION OF GASES BY HEAT.—Of all bodies, gases undergo the greatest change of dimensions on the application of heat. It resulted from Dalton's experiments that 1000 cubic inches of air, on being heated from 32° to 212°, expanded to 1392 cubic inches. It was found by Gay Lussac, in 1804, that 1000 cubic inches of air, on being heated from 32° to 212°, became 1375 cubic inches. The more recent researches of Rudberg, Magnus, and Regnault, show that these numbers are above the mark. Instead of 1375 it ought to be 1367 cubic inches. Hence, on being heated 180 degrees, the volume of a mass of air becomes augmented by $\frac{367}{1000}$ths of the volume it possessed at 32°.

12. Experiments prove that the expansion of air is uniform, that it is augmented by the same quantity for every degree of temperature imparted to it, so that the expansion due to 180° is 180 times the expansion due to 1°. Hence, to find the expansion due to 1°, we have to divide the fraction $\frac{367}{1000}$ by 180: this gives us $\frac{367}{180000}$, or, reduced to its lowest terms, $\frac{1}{490}$. This result may be thus expressed in words;—When atmospheric air, at a temperature of 32°, is heated 1°, it expands $\frac{1}{490}$th of its volume. If raised 2°, the expansion would be $\frac{2}{490}$ths; if 3°, $\frac{3}{490}$ths of the volume which it possessed at 32°. What is true of atmospheric air is true of other gases. They all expand in the same proportion, except those which are near their point of condensation.

13. Supposing, then, that I asked at what temperature

a cubic foot of gas at 32° would enlarge its volume by one-half, you would of course reply, at a temperature of 245° above 32°, for here the expansion would be $\frac{1}{4}\frac{1}{4}$ths, or one-half. If again I asked at what temperature a mass of gas which measures a cubic foot at 32°, would double its volume, you would reply to me, at 490° above 32°, or, in other words, at a temperature of 490+32=522°, as shown by the thermometer.

14. It is easy to show the expansion of air by heat. Let the neck of a retort dip into a vessel of water as in fig. 10; on bringing a spirit-lamp underneath the retort, the air within it expands, and is driven in bubbles through the water. On allowing the retort to cool, the air will shrink to its former dimensions, and the consequence is, that the water, pressed upon by the atmosphere, will follow it and partially fill the vessel. In like manner, in the process of cupping, a glass, with the air within it rarified by heating, is inverted over the wound; the air cools and contracts, and the blood, and even flesh, are forced by the pressure of the atmosphere into the glass, just as the water is forced into the retort.

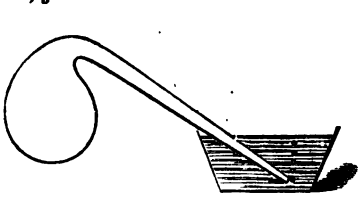


Fig. 10.

15. On its expansion by heat, air becomes lighter, and will, if it can, ascend into the atmosphere. While I write, the flame of a candle is before me; the erect position of that flame is due to the ascent of the column of heated air. I place my hand above the candle, and find it struck by this "hot blast." I pluck a hair from my head, and make it act as a weather-cock; when placed above the flame it is blown upwards. Take a

bent tube, such as that shown in fig. 11, and heat the corner at A by a spirit-lamp; the air will ascend the leg A B, and, to supply its place, a descending current will establish itself in the other leg. If a smoking taper be held at C, the smoke will be carried down, and will make its appearance at B.

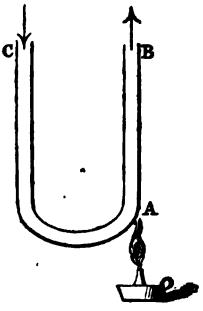


Fig. 11.

16. The products of the combustion of coal-gas are very injurious to health, and it is therefore desirable to have them carried away from the room in which the gas is burned. To accomplish this, Mr. Faraday invented a lamp, the principle and construction of which there will, I think, be now no difficulty in understanding.

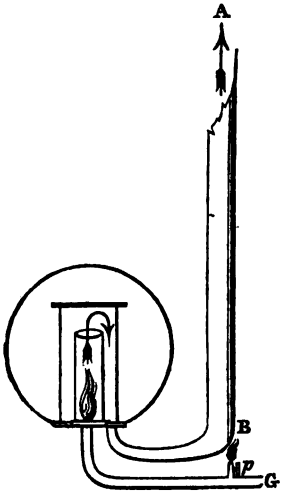


Fig. 12.

The gas enters the lamp from the pipe, G (fig. 12): immediately round the flame is a common glass chimney, and around this again a larger one, which has a plate of transparent mica placed upon the top of it. Round both chimneys is a spherical shade of diaphanous porcelain, not open at the top as ordinary shades are. A B is a tube of bronze, the end A of which communicates with the atmosphere; the other end of the tube communicates with the space between the two glass chimneys. At *p* is a small gas jet, and the first

thing done is to ignite this. It heats the corner, B, of the bronze tube, and thus produces an upward current through the latter. Let the lamp be now lighted, and the chimneys and shade arranged as in the figure. The current of heated gases from the lamp ascends through the inner chimney, and to supply the place of the air displaced at B, the current turns downwards, as shown by the arrow, reaches B, and is carried off through A B into the atmosphere. Thus, you see, not a single particle of the gases generated by combustion enters the room. The noxious nature of these gases may be demonstrated by placing a candle at A. It will be immediately extinguished by the carbonic acid present there. After the lamp has been in action for a little time, the jet, *p*, may be extinguished; for the tube, A B, being once heated by the gases proceeding from the lamp, will itself keep up the necessary current.

17. The following experiment is also instructive:—Let a candle, C, be placed upon a plate, P (fig. 13), and let a glass jar with its mouth open be placed over the candle, a little water being poured upon the plate to prevent the entrance of air at the bottom of the jar. Let a glass chimney, A B, be placed upon the jar. Although in this arrangement the lighted candle communicates with the atmosphere, it will nevertheless go out; for the products of combustion, seeking to ascend, are opposed by the pressure of the external air. Let a piece of cardboard, D E, be now introduced so as to divide the tube, A B, into two halves. The products of combustion choose one-half of the tube and ascend, while the air descends through the other half to supply their place. In this way fresh air is supplied to the candle, and it

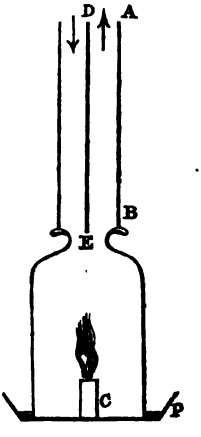


Fig. 13.

burns as long as it lasts. Of course the principle of ventilation here described applies as much to the shaft of a mine as to the tube used in our experiment.

18. It is the currents produced by heated air that ventilate our rooms. The air about the fireplace is carried up the chimney, and the entrance of air through doors and chinks makes good the loss. In this way draughts are produced, which, though they may afflict us with rheumatism, at all events clear away the carbonic acid and supply us with fresh air. In a warm room the heated air will ascend towards the ceiling; if you open a door into such a room and place a candle near the floor, the flame of the candle will lean inward, showing the direction of the air below. If you place the candle near the door-top, the flame will lean outwards, showing the escape of the warm air. In the centre of the doorway the flame stands upright. This simple experiment illustrates a great natural effect produced by the heat of the sun. The torrid regions of the earth are in the condition of our warm room. The heated air of the tropics rises and flows towards the poles, while its loss is supplied by an under-current of heavy air *from* the poles. Were the earth without diurnal rotation, these two currents would flow directly north and south; but, as in the case of the Gulf Stream already described, the motion of the earth from west to east combines with the motion of the air from north to south, and thus we have, in the northern hemisphere for example, a south-westerly current above and a north-easterly one in the lower regions of the atmosphere. The lower current constitutes the trade-wind. But how do we know that the *upper* current exists? No man ever lifted a weathercock so high, yet still we may conclude with certainty that the under-current from the poles is balanced by an upper current towards them. But neither are we without experimental proof of the existence of the upper stream. I cannot, I think, better describe to you this experiment, made by Nature herself, than by translating the account of it

given by Professor Dove, while addressing a public audience in Berlin.

19. "On the night of the 30th of April," says M. Dove, "explosions like those of heavy artillery were heard at Barbadoes, so that the garrison of Fort Saint Anna remained all night under arms. On the 1st of May, at daybreak, the eastern portion of the horizon was clear, while the remainder of the firmament was covered by a black cloud, which soon spread over the east, quenched the light there, and finally produced a darkness so dense that the windows in the rooms could not be distinguished. A shower of ashes now descended, under which the tree-branches bent, and were broken. Whence came these ashes? From the direction of the wind we should infer that they came from the Azores: not so, however; they came from the mountain Morne Garou in St. Vincent, which lies about a hundred miles westerly from Barbadoes. The ashes had been cast into the upper current of the trade-wind, and thus borne forward in a direction opposed to the lower current. A second example of the same kind occurred on the 20th of January, 1835. On the 24th and 25th the sun was darkened in Jamaica by a shower of fine ashes, which had been discharged by the mountain Coseguina. The people learned in this way that explosions previously heard were not those of artillery. These ashes could only have been carried by the upper current, as Jamaica lies north-east from the mountain. The eruption furnishes also a beautiful proof that the ascending air-current divides itself above into two portions, one proceeding towards the North Pole, and the other towards the South; for ashes also fell upon the ship 'Conway' while in the Pacific, at a distance of seven hundred miles south-west of Coseguina."

20. Though the remainder of M. Dove's description does not strictly apply to our subject, still it is so interesting that I think you will not be displeased if I translate it for you:—

"Even on the highest of the Andes," he proceeds,

"no traveller has as yet reached this upper current, and from this fact some notion may be formed of the force of the explosions: they were indeed tremendous on both the instances referred to. The roaring of Coseguina was heard at San Salvador, a distance of a thousand miles. Union, a seaport on the west coast of Conchagua, was in absolute darkness for forty-three hours; and as light began to dawn, it was observed that the sea-shore had advanced eight hundred feet upon the ocean, owing to the quantity of ashes which had fallen. The eruption of Morne Garou seemed to form the last link in a chain of vast volcanic actions. In the month of July, 1811, near St. Michael, one of the Azores, the Island Sabrina rose with smoke and flame from the bottom of the sea. The depth of water was a hundred and fifty feet, the height attained by the island three hundred feet, and it was a mile in circumference. The small Antilles were shaken afterwards, and subsequently the valleys of the Mississippi, Arkansas, and Ohio. But the elastic forces found no vent, and they next sought one on the north coast of Columbia. The 26th of March began as a day of extraordinary heat at Caraccas: the air was calm and the sky cloudless. It was a holiday, and a regiment of troops of the line stood under arms in the barracks of the quarter San Carlos, ready to join in a procession. The people streamed to the churches. A loud subterranean thunder was heard, and was immediately followed by a shock so violent that the Church of Alta Gracia, a hundred and fifty feet high, and supported by pillars fifteen feet thick, was reduced to a heap of rubbish not more than six feet in elevation. In the evening the nearly full moon looked down with mild lustre on the ruins of the town, under which lay the crushed bodies of upwards of ten thousand of its inhabitants. But even here the elastic forces found no outlet. Finally, on the 27th of April, they succeeded in opening the crater of Morne Garou, which had been closed for a century; and the earth, for a distance equal to that

from Vesuvius to Paris, rang with the shout of the liberated prisoner."

LESSON IV.

CONDUCTION AND RADIATION.

1. ON THE CONDUCTION OF HEAT.—If you thrust one end of a poker into a fire, the heat will propagate itself through the metal and finally make itself felt at the other end. This travelling of the heat from particle to particle of the iron is called the conduction of heat, and the metal itself the conductor. You will observe here, at the outset, that this is a very different process from that by which heat, as already described, distributes itself through a liquid. This process is sometimes called *convection;* the heated particles, it will be remembered, rise and diffuse their heat through the cooler ones; but there is no such wandering of the particles in the case of the poker. When a column of liquid is heated at the top, the propagation of heat through it is immeasurably slower than when it is heated at the bottom, for the warm layer of liquid remains at the top, and must thus communicate its heat to the lower ones by the process of conduction, and not by that of convection. With the poker it is immaterial whether you thrust it upwards, through the bars, or downwards; the heat will propagate itself alike from the hot end to the cold one.

2. Metals are the best conductors of heat, but they differ widely from each other in this respect. The first experiments made to determine this conductibility were very defective, nevertheless a certain celebrity still attaches itself to those of Ingenhousz. He coated a number of different bars with wax, and dipping one end of the bars into a bath of hot oil, he was able to trace the progress of the heat by the melting of the wax upon the surface. M. Despretz, however, was the first to

confer experimental accuracy upon this branch of science. He took bars of various metals, and arranged

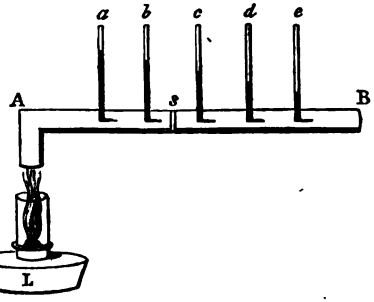


Fig. 14.

each of them as A B in fig. 14. At one end is a lamp L, the flame of which is preserved constant; this communicates heat to the end of the bars: at equal distances asunder, and fitting into cavities made in the bar, are the thermometers *a*, *b*, *c*, *d*, *e*. The heat imparted by the lamp travels through the bar, and the mercury in the thermometer *a* is soon observed to rise; *b* is next affected; the heat reaches the others in succession, and causes them to rise. Fix your attention upon any slice taken across the bar, say at *s*. This slice receives heat from the end A of the bar, and sends it on to the end B. As long as the quantity received from A exceeds that given up to B, the temperature of the slice will increase; but after a sufficient time these quantities will become exactly equal to each other, and thus, though there is a flow of heat through the slice, its temperature remains constant. M. Despretz waited until this condition had established itself throughout the whole bar: his thermometers then ceased to rise; the mercury then stood highest in *a*, and lowest in *e*, gradually diminishing from one to the other. From this he was enabled to calculate, and express in numbers, the conductibility of each bar for heat.

3. The following are the results of the most recent experiments made upon this subject:—

Substances.	Conductibility for Heat.	Conductibility for Electricity.
Silver - - - -	100	100
Copper - - - -	73·6	73·3
Gold - - - -	53·2	58·5
Brass - - - -	23·6	21·5
Tin - - - - -	14·5	14·0
Iron - - - - -	11·9	12·0
Steel - - - -	11·6	„ „
Lead - - - -	8·5	8·27
Platinum - - - -	8·4	7·93
German Silver - -	6·3	5·9
Bismuth - - - -	1·8	1·9

Thus silver stands at the head of the list of metallic conductors and bismuth at the foot. The numbers in the second column express the relative conductive powers of the metals used. I have also added a third column, which shows the conductive powers of the same substances for electricity; and here the suggestive fact will be observed, that the best conductors of the one agent are also the best conductors of the other.

4. Next to the metals, crystals, stones, glass, and similar bodies are the best conductors of heat, but they differ as much among themselves as the metals do. A crystal of quartz, for example, has a conductive power greatly superior to that of a crystal of gypsum: rock salt conducts heat much better than sugar. Flint conducts better than marble. It is perhaps worthy of remark that substances which belong to the animal and vegetable kingdoms are extremely imperfect conductors; and both animals and vegetables are in some measure protected by this property from the injurious effects of sudden changes of temperature.

5. I have already referred to the fact that in a cold room, metals, when touched by the hand, seem coldest, and the woollen fabrics least cold. We are now in a

condition to understand this. The metal is a good conductor, and diffuses the heat communicated to it by the hand quickly through its mass, it thus abstracts the heat speedily from the hand and produces the sensation of cold. Wool, on the contrary, cannot thus dispose of the heat; the superficial layer in contact with the hand is all that the hand has to warm, and the quantity of heat necessary for this is almost inappreciable.

6. You will sometimes see metallic pipes used for the conveyance of steam, and which it is desirable to keep warm, wrapt round with straw bands, coarse flannel, or some other similar material. Were the pipe in contact with the atmosphere it would yield up its heat quickly, but the interposition of the non-conducting material prevents this. Precisely in the same manner the interposition of non-conducting woollen cloth saves our bodies from the abstraction of heat by the chill of the atmosphere. The philosophy of wooden handles to coffee-pots and kettles, the reason why a piece of ivory is interposed, where it is deemed desirable to have a metallic handle to a teapot, and other things of the same kind, will be so evident to you as not to need a word of explanation.

7. Not only do different bodies possess different conductive powers for heat, but in some cases the same body possesses different powers in different directions. Many crystals exhibit this peculiarity. Wood also exhibits it. If the surface of a plate of wood be thinly coated with wax, or with stearine, and a wire be introduced through a small hole in the plate, and heated while in this position, the heat passing from the wire into the wood will melt the wax; but it will not melt it equally well in all directions. Let *a*, *b*, *c*, *d* (fig. 15), be such a plate of wood, and *h* the aperture in which the wire is inserted; the heat passes most

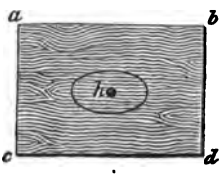


Fig. 15.

freely in the direction of the fibre of the wood, which in the figure is parallel to the sides *a b*, and *c d*; the consequence is that the melted wax forms an oval, with its length along the fibre. If the wood conducted equally well in all directions, the figure melted away would form a circle.

8. I cannot quit this subject without pointing out a very common mistake made in treatises on Natural Philosophy, and repeated by lecturers upon heat. To illustrate the different conductive powers of different bodies, short cylinders of these bodies are taken and placed upright upon a heated surface—for example, upon the flat lid of a metallic vessel containing boiling-water. A bit of wax or of phosphorus is placed upon the upper end of each cylinder, and it is stated that the cylinder on which the wax is first melted, or the phosphorus first ignited, is the best conductor.

Now, if two cylinders an inch in length, one of iron and the other of bismuth, be each furnished with its bit of phosphorus, and placed at the same instant upon the heated surface, it will be found that the phosphorus upon the bismuth ignites sooner than that upon the iron. Hence, according to the lecturers and books referred to, bismuth ought to be a better conductor than iron. By reference to our table at page 267, it will, however, be seen that bismuth is greatly inferior to iron as a conductor of heat; it stands lowest among the metals, and is actually less endowed in this way than some non-metallic bodies. How then are we to reconcile this apparent contradiction?

9. In fact, when such a mode of experiment was adopted, it was wholly forgotten that something else than mere conduction came into play and modified the result. It is undoubtedly true that the greater the conductive power of our cylinder, the greater will be the quantity of heat taken up by it in a given time from the hot surface upon which it rests, and thus iron will take up more heat than bismuth. But if you look at the table at page 250, you will see that while iron possesses a

specific heat of 0·11379, the specific heat of bismuth is only 0·03084. What is the consequence? Why, that though bismuth takes in far less heat than iron, yet on account of the low specific heat of the former metal, the small quantity which it takes in heats it considerably, and thus produces a speedy effect upon the phosphorus. I am the more induced to call your attention to this, from the fact that during a recent public examination nineteen out of twenty-two candidates, misled by what they had heard in lectures and read in books, fell into the error of supposing that the experiment to which I have referred was a true test of conduction. The proper way would be to wait until the body has taken in as much heat as it can: that body then which is heated to the greatest distance is the best conductor.

10. ON THE RADIATION OF HEAT.—If you stand before a fire without touching it, you feel heat, and if a goose be suspended before it, you may, without at all bringing it into contact with the fire, roast the goose. Here there is no conductor between the goose and the fire, yet the heat reaches it and cooks it. You may reply that there is air between both, and that *it* may be the carrier of the heat. But you may allow a current of air to pass across between both; you may blow with a pair of bellows between them; you blow away the air, but you cannot blow away the heat; it will cross the current of air and reach the goose as before. Nay, you might by suitable means take away the air altogether, and still find that the heat would cross the vacuum. Heat which thus travels without the interposition of a conductor is called *radiant heat*: it passes from a warm body exactly as light is radiated from a luminous one.

11. There is a striking analogy between the action of radiant heat and of light. Heat can be reflected like light; it can be refracted, it can be polarized. You can cause two rays of light so to act upon each other that they shall mutually destroy each other's actions, or, in other words, by adding light to light you can produce darkness; and so in like manner by adding heat to heat

you can produce cold. For the meaning of the terms which I have here used, I must refer you to the article upon Light. We soon notice striking differences in the manner in which this radiant heat is received by different bodies, some bodies absorb it greedily, others reject it, those bodies which absorb it greedily also radiate it plentifully, while those which do not absorb it readily are feeble radiators. The metals, though the best conductors, are the worst radiators, and instead of absorbing radiant heat, they reflect it. If you place a bright silver teapot containing cold water, before a fire, the water will warm with extreme slowness, for nearly all the heat that falls upon the teapot is reflected. If the same teapot be coated with lamp-black, or even with a thin sheet of varnish, the warming of the water will be immensely accelerated, for the coating absorbs the heat and communicates it to the metal. Let us now reverse the experiment. Let two teapots, one polished and the other coated with lamp-black, be filled with hot water, and let a thermometer be immersed in each. It will be found that the water in the blackened vessel cools more quickly than that in the polished one. This effect is not due to the abstraction of heat from the teapot by the cold air; were this the case the bright teapot would be chilled quickest, for the lamp-black is a bad conductor, and thus tends to check the flow of heat to the air. The quicker cooling of the blackened vessel is due solely to the fact that the lamp-black, though it conducts much worse, radiates much better than the metal.

12. A very thin film on the surface of a body is sufficient to alter its power of absorption and radiation. Let the quantity of heat radiated by clean lead be 19; the same lead, when tarnished by contact with the atmosphere, will radiate a quantity expressed by the number 45, or nearly 2½ times as much as before.

Experiments on this subject may be satisfactorily performed with the air thermometer of Leslie. A description of the best instrument would necessitate a

knowledge of certain electrical actions, and therefore such a description cannot be introduced here. The air thermometer is represented in fig. 16. It consists of two thin glass bulbs, united by a tube bent as in the figure. The bent tube contains a coloured liquid, which stands, let us suppose, in one leg at *a*, and in the other at *b*. If heat be communicated to the bulb above *a*, the air within it will expand, press down the surface *a*, and lift the surface *b*; the descent of the liquid is measured by a scale which is attached to the instrument. Air, as we know, is much more expansible than mercury, and the thermometer here described is proportionally more sensitive than the mercurial thermometer.

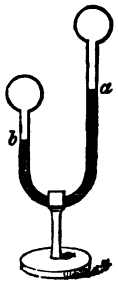


Fig. 16.

13. Radiant heat is subjected to the same laws of reflection as light and sound. I have in a former article described the parabolic mirror, and would now recommend you to turn to the place and refresh your memory upon the subject. Let A B (fig. 17), be such a mirror,

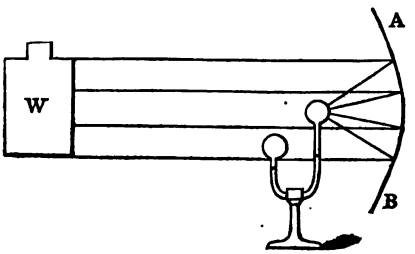


Fig. 17.

and let W be a cubical vessel filled with hot water. The parallel rays of heat which proceed from W are all collected to a point by the mirror A B, and if the bulb of the air-thermometer be placed in the focus, the

liquid in the stem underneath it will immediately sink. If one side of the cubical vessel be kept bright, and another be coated with lamp-black or white-lead, it will be seen, on turning the coated surface towards the mirror, that the depression of the liquid is greater than where the heat radiates directly from the metal.

14. In lecture experiments, two such mirrors are commonly used. Let a hot sphere of metal be placed upon the stand in the focus of the mirror A' B' (fig. 18), the heat will be reflected from A' B' in parallel lines, and will be collected by the mirror A B into its focus. If the bulb of the air-thermometer be placed in this focus, the liquid column underneath will be forcibly depressed. That this is due to the reflected heat, and not to the heat falling directly from the ball upon the thermometer, may be proved by causing the thermometer to approach the ball; if the action were due to the direct heat, the depression of the liquid would be augmented, but the contrary is observed; when the bulb quits the focus, the liquid rises.

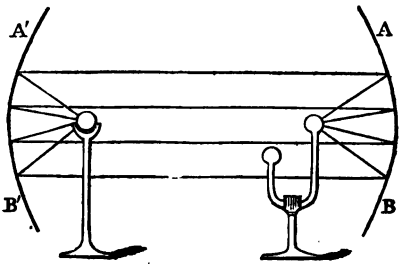


Fig. 18.

The mirrors, when large, are sometimes placed one above the other; one, for example, is placed on a table, and the other drawn up to the ceiling by means of a rope and pulley. Placing a red-hot ball in the focus of the upper mirror, a lucifer-match may be ignited, and some other inflammable substances caused to explode;

or even a fowl might be roasted, by placing it in the focus of the lower mirror.

15. Let me now endeavour to apply the knowledge which we have gained to the explanation of a beautiful natural phenomenon—the formation of Dew. On a fine autumn morning you may see the grass-blades loaded with liquid pearls, while metals and other bodies exposed to the night-air remain quite dry. Let us prepare the way for the explanation by calling to mind one or two facts. The pure vapour of water is as transparent as the air; and when I stated, in describing the Geyser eruption, that the water was wrapped in clouds of steam, I expressed myself popularly, but not with scientific accuracy. This visible cloud is not steam, but water in a fine state of division: fog, in like manner, is not vapour, but a collection of water particles: pure steam or vapour, it must be remembered, is transparent, and invisible in the air.

The warmer the air is the greater is the quantity of vapour which it can preserve in this transparent state. During some days of great serenity, especially in autumn, the air contains a large quantity of transparent vapour, and it is in the nights of such days that dew is deposited most copiously: you will find no dew deposited on a cloudy or a windy night.

16. Imagine, then, a meadow lying at night under a serene sky. The heat imparted to the grass-blades during the day is now sent off from them by radiation; they are excellent radiators, and send out the heat they possess lavishly into space. Were clouds in the heavens, they would intercept and return a portion of the heat sent out, and thus protect the grass from being chilled; but when no clouds exist, it is a case of pure loss, as far as the grass is concerned; the heat once radiated returns to it no more.

Grass is also a very bad conductor, and it is therefore unable to draw from the earth on which it grows a supply to make good its loss by radiation. The consequence is, it becomes more and more chilled; and if you

place a thermometer among such grass, you will always find its temperature lower than that of the air a few feet above the meadow.

The little grass-blades thus chilled condense the atmospheric vapour upon their surfaces. The warmth gained by the precipitation of the moisture is again radiated, and thus throughout the night the grass is kept cold. The process of condensation continues, and the quantity of moisture deposited is at length so great that we see it in the morning as shining pearls weighing down the blades of grass. What has been said regarding grass applies especially to those fine cobwebs which we see in the country hedges; they also become chilled, and liquid spherules are ranged like beads along the tiny threads.

17. NOTE ON THE NATURE OF HEAT.—In the foregoing article I have alluded to what is called the material theory of heat. Within the last few years scientific men have more and more seceded from this theory, and the belief is now gaining ground that heat is not a kind of matter as once supposed, but that it is a motion of the particles of matter. A vibrating string or bell communicates its motion to the atmosphere; the motion reaches our ears and produces the sensation of sound. A luminous body is supposed to be also in a state of vibration, and its motion is transmitted, not by air, but by a finer medium, called ether, to the nerve of the eye, thus producing the sensation of light. So, also, a warm body is one whose particles are in a state of vibration, communicating this motion also to the ether, and producing, when they strike the proper nerve, the sensation of heat. The waves or undulations excited in the ether by a warm body differ from those produced by a luminous body, by being of greater length and of longer duration. The same ray may, by falling upon one nerve, produce the sense of light, and by falling upon another, produce the sense of heat. The sunbeams probably act in this way. The molecular motion which we call heat may be produced by mechanical

means. Every time that ordinary mechanical motion is destroyed or retarded, heat is developed. When a stone falls to the ground, or a cataract casts its waters over a ledge of rocks, the checking of its motion upon striking the earth is accompanied by the development of an amount of heat exactly equivalent to the quantity of motion destroyed. By the compression of air you can produce heat sufficient to ignite tinder. In some books the air is described as a sponge holding the heat within it; and it is said that the heat is squeezed out by the act of compression. The new view says, "No! it is the mechanical force exerted in compressing the air that has thrown the particles into the motion that we call heat." We know exactly how much heat is developed by the expenditure of a given amount of force. We can calculate the quantity of heat generated by a cannon-ball on striking a fortress, if we know the velocity of the ball. We know that if our earth were brought by a shock to a state of rest in her orbit, the amount of heat generated would be equal to that produced by the combustion of fourteen earths of solid coal; and if afterwards the earth fell into the sun, which she would do if her orbital motion were destroyed, the amount of heat generated by the shock would be four hundred times greater. I cannot enter fully into this subject here: it is new, and not quite suited for boys. Nevertheless, I was unwilling to leave you in ignorance of the notions now entertained regarding the nature of heat. The material theory is, as I have said, losing ground more and more; and it is probable that in a few years it will not number among its adherents a single individual whose opinion is of any authority in science.

JOHN TYNDALL.

SUMMER HEAT.

SEE, how at once the bright effulgent sun,
Rising direct, swift chases from the sky
The short-liv'd twilight; and with ardent blaze
Looks gaily fierce through all the dazzling air.

He mounts his throne; but kind before him sends,
Issuing from out the portals of the morn,
The genial breeze to mitigate his fire,
And breathe refreshment on a fainting world.
Great are the scenes, with dreadful beauty crown'd
And barbarous wealth, that see, each circling year,
Returning suns and double seasons pass:
Rocks rich in gems, and mountains big with mines,
That on the high equator ridgy rise,
Whence many a bursting stream auriferous plays:
Majestic woods of every vigorous green,
Stage above stage, high-waving o'er the hills;
Or to the far horizon wide diffus'd,
A boundless deep immensity of shade.
Here lofty trees, to ancient song unknown,
The noble sons of potent heat and floods,
Prone-rushing from the clouds, rear high to Heaven
Their thorny stems; and broad around them throw
Meridian gloom. Here, in eternal prime
Unnumber'd fruits, of keen delicious taste
And vital spirit drink, amid the cliffs
And burning sands that bank the shrubby vales,
Redoubled day; yet in their rugged coats
A friendly juice to cool its rage contain.
Bear me, Pomona! to thy citron groves;
To where the lemon and the piercing lime,
With the deep orange, glowing through the gloom,
Their lighter glories blend. Lay me reclin'd
Beneath the spreading tamarind that shakes,
Fann'd by the breeze, its fever-cooling fruit.
Deep in the night the massy locust sheds,
Quench my hot limbs; or lead me through the maze,
Embowering endless, of the Indian fig;
Or thrown at gayer ease, on some fair brow,
Let me behold, by breezy murmurs cool'd,
Broad o'er my head the verdant cedar wave,
And high palmettos lift their graceful shade,
Or, stretch'd amid these orchards of the sun,
Give me to drain the cocoa's milky bowl,
And from the palm to draw its freshening wine;
More bounteous far, than all the frantic juice
Which Bacchus pours. Nor, on its slender twigs
Low-bending, be the full pomegranite scorn'd;
Nor, creeping through the woods, the gelid race

Of berries. Oft in humble station dwells
Unboastful worth, above fastidious pomp—
Witness thou best Anâna: thou the pride
Of vegetable life, beyond whate'er
The poets imag'd in the golden age:
Quick let me strip thee of thy tufty coat,
Spread thy ambrosial stores, and feast with Jove!

WINTER.

'Tis brightness all, save where the new snow melts
Along the mazy current. Low, the woods
Bow their hoar head; and, ere the languid sun,
Faint from the west, emits his evening ray,
Earth's universal face, deep hid, and chill,
Is one wild dazzling waste, that buries wide
The works of man. Drooping, the labourer-ox
Stands cover'd o'er with snow, and then demands
The fruit of all his toil. The fowls of heaven,
Tam'd by the cruel season, crowd around
The winnowing store, and claim that little boon
Which Providence assigns them.

THOMSON.

Biography.

SIR WILLIAM HERSCHEL.

BY HUGO REID.

1. THIS distinguished astronomer was born in the city of Hanover, in the north of Germany, in the year 1738. Though he made England his home, acquired his fame and died in this country, we should not forget that he was a German by birth and extraction; a member of that great German race which has done so much to advance the human intellect, and which can boast of the illustrious names of Luther, Kepler, Leibnitz, Handel, Haydn, Mozart, Kant, Schiller, Goethe, Beethoven, Weber, and the two Humboldts. Herschel was brought up to the same profession to which his father belonged—that of a musician; and at the early age of about fifteen was placed in the band of the

Hanoverian Foot Guards; but finding little prospect of getting on in his own country, or being desirous of more rapidly advancing his fortunes, he came in 1757 to England, where the Hanoverian Elector reigned, as King of Great Britain and Ireland, under the title of George II.

2. He was unable to find employment in London, and for some time had many difficulties to encounter, such as might be anticipated of a youth, unknown and without friends, struggling with scanty means in a foreign land. Fortunately he at last came under the notice of the Earl of Darlington, who employed him to instruct the band of the Durham Militia. From this time his progress was sure and rapid. At the conclusion of his engagement, he settled as a teacher of music in the south-west of Yorkshire, being often employed to conduct the concerts and oratorios in Leeds and other towns in the vicinity. In 1765 he was appointed organist at a church in Halifax, and in the following year, removed to Bath, having obtained the situation of organist to the Octagon Chapel. He lived in that city for some time, and there met with much success as a teacher of music and conductor of public concerts.

3. Although Herschel was an able and accomplished musician, his genius lay in another direction; his tastes were for science:—philosophy, metaphysical and mathematical, was what had the greatest charms for his mind; and from his early youth he had embraced such opportunities as occurred to him of improving himself, and gratifying his peculiar tastes in the study of French, metaphysics, algebra, geometry, &c. He steadily pursued the profession in which his lot had been cast; and as we have seen, secured by that profession a position of respectability and independence. He was now enabled to devote his leisure time to such studies as most interested him; and these led him ultimately to astronomy, in which he was destined to become so distinguished. It has been said that he was

led by music to mathematics, by mathematics to optics, and by optics to astronomy, where he rested. It is certain that music is a mathematical subject; and one of the earliest writings of William Herschel was an answer to Peter Puzzlem in the 'Ladies' Diary,' who had propounded the question, "The length, tension, and weight of a musical string being given, it is required to find how many vibrations it will make in a given time, when a small given weight is fastened to its middle and vibrates with it."

4. Having acquired some knowledge of astronomy from the works of the self-taught writer and popular lecturer, James Ferguson, he became desirous of witnessing with his own eyes some of the wonders of the heavens as displayed in the telescope. It is said, that his being unable to purchase a good instrument first led him to the idea of constructing one for himself. This was a work of no small difficulty for one who had no previous instruction or practice in the art. But by his mechanical genius, perseverance, and ingenuity, he overcame these difficulties; and in time succeeded in making very superior telescopes, with which he was enabled not only to gratify his desire to see what was already known to be within the reach of the telescope, but to make new and original observations, and extend greatly our knowledge of celestial phenomena.

5. The science of astronomy had made great progress since the times of Copernicus, Kepler, and Galileo. The Copernican system had become established, and Sir Isaac Newton had developed the true rationale of the planetary motions by unfolding the principle of Universal Gravitation, and the laws of its operation. The satellites of Jupiter, and Saturn's ring and several of his satellites, had been discovered; but still the number of known leading or primary planets remained, as in the oldest times, before the telescope was invented. Mercury, Venus, the Earth, Mars, Jupiter, and Saturn were generally believed to be the only planets that revolved round the Sun; the orbit of

Saturn being then viewed as the limits of the solar system. It was the glory of William Herschel to be the first to extend these limits—to discover a new principal planet, at double the distance of Saturn from the Sun, many times larger than our earth, and having a system of satellites waiting upon him, as in the case of the only two known planets exceeding him in magnitude—Jupiter and Saturn.

6. In 1781, when surveying the heavens with one of the superior telescopes which he had made, he discovered what he at first supposed to be a comet. Further examination proved that it was a planet; and he gave it the name of *The Georgium Sidus*, in honour of George III., who then reigned in Great Britain. By some it was called *Herschel*, in honour of its discoverer; but it is now always named *Uranus*, as it is considered better that, like the other planets, it should take its name from the mythology of the ancients. This planet has now been quite established as a member of the solar system, though it has not made one complete revolution in its orbit since its discovery in 1781, its period being eighty-four years. Its diameter is about 35,000 miles, more than four times that of our earth; but its distance is so great that it is invisible to the naked eye, although so many times larger than Venus or Mars. It is 1,822,000,000 of miles from the Sun.

7. Not only was this a very interesting discovery in itself, adding a new and important member to the planetary system, and extending so greatly the known boundaries of that system; but, as often happens, it led to another great discovery. The course which this planet should pursue, according to the established laws of the solar system, was soon ascertained by astronomers; and so carefully and correctly was this done, that when, after forty years, it was found to deviate considerably from the calculated orbit, astronomers were thereby led to the discovery of a previously unknown planet, now called Neptune, at a vast distance beyond Uranus,

whose attraction caused those deviations of Uranus, and thus singularly led to the great discovery of their previously unknown cause, and added another principal planet to the solar system.

8. The discovery of Uranus was the foundation of Herschel's fame and fortune. He was elected a fellow of the Royal Society, the most distinguished scientific body in the kingdom; and the Society's gold medal was awarded to him. At the same time, his great discovery brought him under the notice of the king, George III., who appointed him to the honorary office of his astronomer, but with the substantial gift of a salary of 400*l.* per annum: a memorable and judicious exercise of the royal bounty, as it enabled Herschel to devote himself entirely to the pursuit of astronomical science, which he enriched by a succession of brilliant and important discoveries. He settled first at Datchet, then at Slough, near Windsor, which he rendered famous.

9. It was Herschel's glory, in several of his great discoveries, to open up to us entirely new regions: this was pre-eminently the case in the next great discovery of this remarkable man. For ages the fixed stars had excited the interest of astronomers, and at the same time perplexed them in this, that they could not acquire any positive information regarding them: they could admire them, as the unlettered peasant did; they could take note of their positions in relation to each other; but beyond knowing that a little more exactly, the learned astronomer, in respect to the fixed stars, had no advantage over ordinary observers. Even after the telescope was invented, it was found to give little information regarding these stars: viewed through the telescope, they did not expand into discs, like the planets, but remained brilliant points; and we had no means of learning anything as to either their magnitudes or their distances from us. It was known that their distances were very great, for they preserved the same positions in relation to us and to each other when

viewed from the opposite points of the earth's orbit, that is, from two points distant no less than one hundred and ninety millions of miles from each other.

10. We know that objects at a little distance from us appear to have changed their relative positions, when we change our position; that bodies very remote appear fixed amongst each other, or to change very little, by any movement we make. This apparent change in the position of an object, caused by a change in the position of the observer, is called its *parallactic motion.* The fixed stars exhibited no parallactic motion when viewed from two points at the greatest distance we can command; the diameter of the earth's orbit shrinking into a point when compared with the vast distance from us to any of the fixed stars. Hence at all seasons the north polar star is found in the north, the earth's axis pointing towards it, however differently it may be inclined towards the Sun at different times.

11. Herchel set himself to endeavour to solve this great problem of the distance of the fixed stars. He did not succeed; though it has been accomplished by later astronomers. But though unsuccessful as to the direct object of his search, in the course of that search he made a discovery of great interest. The parallactic motion of the fixed stars, if any such motion could be found, must be very small, and therefore very difficult, and requiring very delicate measurements to ascertain it. Now there are many of the fixed stars which, appearing single to the naked eye, are found, when examined by the telescope, to be double or triple, that is, to consist of two or three stars set close to each other. This might be accidental, that is, not owing to the stars being in any way connected, or even near each other; but one might be far beyond the other, nearly in the same line of vision as seen by us. Herschel thought that such stars, appearing so very near each other, might, when carefully examined, afford some indications of change of relative position as the earth moved to opposite points of its orbit. He set himself

to observe the positions of these double stars, and found no such motion as would be caused by our orbitual motion; but in time he did observe a regular progressive motion between the two or three stars; so slow, that many years were required to ascertain it with certainty and precision. And it was not till the year 1802, about twenty-five years after he had commenced the inquiry, that he was enabled to arrive at a positive conclusion regarding the character of these motions. In that and the two following years, in papers read before the Royal Society, he announced that, among the fixed stars, there are systems composed of two stars revolving about each other in regular orbits: these are termed *binary* stars. The orbits of several of those known are completed in various periods, from thirty-one to upwards of seven hundred years; one, that of a star in the constellation Hercules having completed two revolutions since its motion begun to be observed.

12. This was one of the grand discoveries of astronomy. These stars had hitherto defied all attempts to gain any knowledge of their nature and phenomena. They appeared inaccessible to human research, too remote for us to do anything but admire their beauty, and wonder at the mystery with which they were invested. Were they mere glittering points, or, as some conjectured, suns like our Sun, with planets and comets revolving round them? All was conjecture and speculation regarding them. At last the careful observation and patient industry of William Herschel revealed one great phenomenon amongst them—regular revolution in an orbit. Now this is the characteristic of the motions of the solar system; and here at one step, from utter ignorance relating to them, and hopelessness of any end to that ignorance, we acquired a knowledge of a phenomenon amongst them like the phenomena we know in our own system. This was the first leap from total darkness into some degree of light respecting the fixed stars; and will ever render memorable the name of William Herschel.

13. Another great discovery of Sir William Herschel related to the fixed stars, and to our position in respect to them. These celestial bodies had acquired the appellation of *fixed*, in contradistinction to the planets and comets, which move about amongst the stars, while those called fixed always retain the same positions in relation to each other. Thus while the planet Jupiter is seen at various parts of the starry heavens—now near one constellation, now moving from it, entering another, passing it, and so on till he makes a complete circuit of the heavens—the stars in the constellation Ursa Major (Great Bear), or Orion, remain in the same relative positions now as they always have done, form the same figures, and appear, to judge from the last two thousand years, as if each really were fixed in one point of the celestial sphere. But when telescopes had been invented, and men had better means of observing with minute accuracy the positions of stars, it was found that some of the fixed stars really were changing their places.

14. Herschel applied himself to the subject, and found reason to believe that the stars in one part of the heavens were opening out or spreading from each other, while those in the opposite quarter were becoming more crowded. This he explained on the supposition that our system—the Sun with all his attendant planets, satellites, and comets — was in motion towards the quarter where the stars were appearing to open out, and from the quarter where they appeared to be becoming more closely set. This is no doubt opposed to the popular notion, that the Sun is *fixed;* but many astronomers, however, had previously thought it probable that the Sun had an onward motion through space; not only because motion seems to pervade the universe, but because the Sun was known to rotate, and it was not probable that a body would be suspended in free space, with a rotatory movement and no other motion. This explanation of certain of the displacements noticed amongst the fixed stars is now

generally adopted, and it has even been calculated by astronomers that his rate of motion (in which the planets and comets participate—being carried along with him) is about 422,000 miles a-day.

15. Besides these three great discoveries, Herschel made many others, of less interest and importance; but which contributed greatly to the progress of astronomical science. In many of his astronomical operations and calculations, he was assisted by his sister, Miss Caroline Herschel, a woman of great ability and love for science. He married a widow, Mrs. Pitt, by whom he had one son, the present distinguished astronomer, Sir John Herschel. He was knighted in 1816, a compliment conferred upon him in acknowledgment of his great services to science; and died in 1823, in the eighty-third year of his age.

16. Very few astronomers have made more numerous and more important additions to our knowledge of the heavens. He discovered Uranus and his six satellites, and that these satellites revolve from east to west, in a direction opposite to that which prevails in the solar system. He discovered the rotation of Saturn's ring, and the exact time of rotation of Saturn and Mars. He first made known the remarkable phenomena of the motions of the binary stars; and showed the probability of a motion of the whole solar system, with its direction. He also threw great light upon the subject of the "Construction of the Heavens,"—that is, the arrangement of the stars; and ascertained the invisible heating rays of the Sun, placed beyond the red rays of the solar spectrum.

17. All this was done by a man who was brought up to the profession of a musician, who was self-taught, as to his other acquirements, and who was forty years of age before he was able to quit his original occupation and devote himself to science; a very remarkable instance indeed of what may be done by industry, perseverance, and a diligent use of those leisure hours which every one has to spare from his ordinary avoca-

tions; and which, if well spent, are sure to yield a rich reward to every one in happiness and self-improvement at least; though but few can hope to reach the fame, honour, and glory of having been a great discoverer, which Sir William Herschel attained by a good use of his leisure time.

HUGO REID.

Natural Philosophy.

LESSON I.

RADIATION.

BY ROBERT HUNT.

1. LIGHT.—The alternations of day and night, regulated by the appearance and disappearance of the sun, must prove to every one that a most intimate connection exists between the phenomenon of LIGHT and that enormous orb around which the earth revolves. Our world is a spheroid, which, having a motion around its axis, is regularly advancing one section of its surface towards the sun, while a corresponding portion is as uniformly receding from it. To the inhabitants of that division which is advancing, the sun is said to be rising; it is morning, and the industrious begin the labours of the day. To the men who dwell upon those lands which are receding, the sun is regarded as setting—the quiet of evening invites them to repose—sleep naturally following the loss of light. If we suppose the larger circle in the accompanying figure (1) to represent the sun and the smaller one the earth, then admitting the former to be the source of illumination, and the latter the recipient of the light, a very brief consideration of motion around an

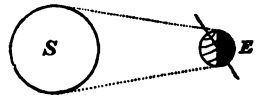


Fig. 1.

axis in the smaller body will render the fact evident, that the side of the earth facing the sun will be in daylight, while the other hemisphere will be under the cloud of night. With those variations in the length of the day and night—in the duration of light and darkness—which are dependent upon the annual motion of the earth around the sun—the Seasons—it is not proposed to deal in this section.

2. The sun is the great original source of light to the earth; our satellite, the moon, is but as a mirror, reflecting some of the solar rays back to us, and all the planets, of our system, shine in the blue vault above, but by reflected beams. Many of the fixed stars, however, are suns shining with their own light, and illuminating other spheres with their rays, as our sun pours all the blessings of light upon our earth. We say the sun is the source of light, yet we have to confess our ignorance of what this principle or agent is by which we see. We know it by its effects—the *cause* which produces these effects is, apparently, beyond the reach of human intellect. An important problem, connected with the source of this illuminating power, has received a satisfactory solution. It was desirable to determine if the light of the sun came from a mass of solid matter intensely heated, or from a gas in some condition of combustion. By having previously examined into the nature of the light proceeding from a sphere of white hot iron, and that which is propagated from a gas-flame, certain facts connected with the phenomena, known as the polarization of light—to be hereafter explained—were determined; and these have enabled the astronomer to prove that the light of the sun is derived from a gaseous envelope, to which has been given the name of the *photosphere* or light sphere.

3. Artificial light can be produced in various ways, which it is important to remember. By hammering a piece of iron briskly it soon becomes hot, and eventually it grows *red hot*, or gives out *red light*. By rubbing pieces of dry wood together we may set them

on fire; that is, we develop *heat* and *light*. All bodies, whatever may be their character, begin to emit light at the same temperature; and whether the experiment is tried with a piece of inflammable paper, a bar of iron, or a block of stone, they equally begin to shine with light when they acquire a temperature, indicated by about 1000° on the scale of Fahrenheit's thermometer—and not before.

4. Violent mechanical disturbance occasions then the development of this principle, whenever powerful chemical changes occur, we have luminous phenomena, and the excitement of electricity gives rise to extraordinary manifestations of light. Phosphorescence, as it is called, or the shining of phosphorus in the dark, and the evolution of light from decaying vegetable and animal matter, is due to chemical changes; and the phosphorescence of living animals is probably due to the same cause, under the influence of nervous excitement.

5. Such being the conditions under which we know light to be produced upon this earth, it becomes probable that one or more of these causes may be active in maintaining the disturbance, which appears necessary, to secure the continuance of that unceasing flood of light which the earth and the other planets receive from their solar centre.

6. Supposing we are in a dark room, and a point of light, such as a small taper, is introduced, all the bodies in that apartment are more or less illuminated. The rays from the taper spread in every direction, and enable the eye to distinguish objects, by the reflection of these rays from the surfaces upon which they fall back to that organ of vision. Here we have two striking facts—the passage (*transmission*) of light in radiant lines, or *rays*, in every direction from the source of illumination, and the turning back of these rays, or their *reflection*, from the bodies illuminated. This we must endeavour to comprehend. Instead of employing a candle as our source of light, let us admit a fine sunbeam through

a small hole into the dark room, a white spot of light will appear upon the floor, and the apartment is partially illuminated thereby, because the surface of the floor reflects the rays to the ceiling and walls. But if we place, to receive the ray, some body which has but very slight powers of reflexion, such as a piece of black velvet, and adopt the precaution of preventing any radiations, except the direct sun-rays, from entering the hole, the result is that the room remains dark, except the small round spot of light formed upon the velvet. If we place a sheet of white paper to receive the ray, it will be *dispersed* and reflected from that surface; and if we use a polished piece of steel or a looking-glass, we shall throw an image of the spot of light, upon the wall, exactly corresponding to the image formed on the floor. In the first example nearly all the light is *absorbed* by the black velvet; in the second it suffers *dispersion*, is reflected in all directions; and in the third is *reflected*, with but little dispersion, along a well-defined line.

7. Light, therefore, is liable (1.) to be *absorbed* by some substances, (2.) it undergoes *dispersion* in different degrees from others, and (3.) it is *reflected*, either entirely or partially, from such as are capable of receiving a high polish.

8. The round spot formed upon the floor is an image of the disc of the sun. If the eye, protected from injury by a piece of dark glass, is placed in the path of the ray, the whole image of the sun will be seen; or if the experiment is made during an eclipse of the sun, the image formed will exactly correspond with that of the bright portion of the sun, the other parts being cut off. This may be simply illustrated. Take a lighted candle, fig. 2, and having made a fine pin-hole in a piece of cardboard, place it in such a manner that the rays from the candle pass through the hole and fall upon a screen—an inverted image of the candle will thus be formed upon it. From every point of the flame, *light* has passed through the pin-hole in straight lines, so that the hole is the vertex of a cone prolonged in both directions. The

image of the sun is produced in the same manner; and

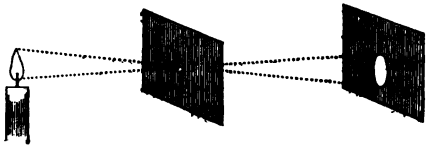


Fig. 2.

the beautiful pictures formed in the camera-obscura, or dark chamber, are dependent upon these conditions.

9. Light, therefore, progresses in straight lines from every part of any luminous body. For its progress *time* is necessary. If a point of light is suddenly extinguished, and two observers are at different distances from it, it will not disappear to each at precisely the same time. The velocity is too great to render this appreciable in any experiment of an ordinary kind on this earth, but some astronomical phenomena render it quite evident. The planet Jupiter has several moons, which are often eclipsed by, or eclipse portions of the planet, accordingly as they pass behind it or over its disc. Now Jupiter varies greatly in its distance from the earth; the periods when these eclipses and emersions take place are exactly known, and it is found that they become visible nearly fifteen minutes sooner when the planet is at its least, than when it is at its greatest, distance from us. While a ray of light is passing from any of the stars to the earth, the earth is moving onward in its orbit round the sun, consequently between the time when the ray leaves a star, and when it reaches the eye of an observer on the earth, the latter will have shifted his place, and the star will consequently appear removed from its true place in the direction in which the earth is moving. This astronomical phenomenon is called the *aberration of light*, and observations founded on it confirm the results obtained by those of the eclipses and emersions of Jupiter's satellites, viz., that

light travels at the enormous velocity of 191,515 miles in a second of time. To form some idea of this velocity it will be sufficient to conceive a cannon ball fired with the greatest force from the sun, and continuing its velocity unabated till it reaches the earth, it would require more than seventeen years to traverse the space over which a ray of light passes in seven minutes and a-half. Notwithstanding this high velocity, it has been demonstrated, that, if the nearest of the fixed stars were suddenly extinguished, we should not notice its disappearance for five years, the last ray of light leaving it requiring that time to pass through the intermediate space.

10. Light radiating from any luminous body, diffuses itself as the distance from its source increases. This is capable of easy illustration in this way. Let a candle, fig. 3, be placed behind an opaque screen in which are

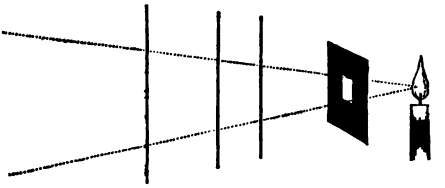


Fig. 3.

pierced a number of holes over one square inch of its surface. Now, upon a sheet of white paper placed immediately behind the screen we shall see specks of light marking out a square inch. As the sheet of paper is removed further from the screen, the space illuminated increases, and at the same time the intensity of illumination diminishes. And if we remove the paper to regular distances we shall discover that this increase being, indeed, as the squares of the distances from the vertex, indicates a diverging pyramid of rays..

The shadow of any body, larger than the source of light by which the shadow is produced, in like manner

enlarges uniformly with the increase of distance. But if the body is smaller than the illuminating source, the shadow as regularly diminishes.

11. Photometers—as instruments employed for measuring the relative illuminating powers of lights are named—are usually constructed upon the principle of measuring the distances necessary to produce equally bright spots of light upon a screen, or equal intensities of shadow. For example, it is desired to know the illuminating power of a gas-flame as compared with that of the flame of a wax candle. If they are placed, fig. 4, side by side, and the light from each is made to

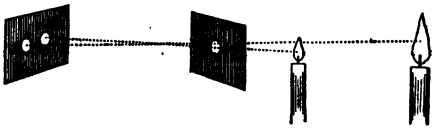


Fig. 4.

pass through a hole in a screen, and fall upon a white sheet of paper, placed to receive it, two spots will be formed, one spot will appear very much brighter than the other, the candle being kept at the same distance from the paper, the distance between it and the gas-flame is increased, until the two spots of light are of precisely the same character; the difference then between the distances of the two illuminating bodies will give the measure of their relative intensities. By a little ingenuity, it will be seen, the arrangements of a photometer may be greatly varied—so as to render the instrument portable and its indications easily understood. Light progresses in straight lines when traversing any homogeneous medium, but if there is any variation in the density of the media through which it passes, as in air, water, or glass, it is bent or *refracted* out of its former path. Or, if any medium is interposed in the path of a ray, which will not allow of the transmission

of light, it is then turned back, or suffers *reflexion*. As many very important phenomena depend upon the *refraction* and *reflexion* of light, the laws which regulate these conditions must be understood.

LESSON II.

REFRACTION AND REFLEXION OF LIGHT.

1. Refraction, a term derived from the Latin, signifying *breaking* back, takes place whenever a ray of light passes from one medium, as air, into another which is denser than it, as water—or the contrary. When we view a body under water, we do not see it in the place which it actually occupies. If the spot A, fig. 5,

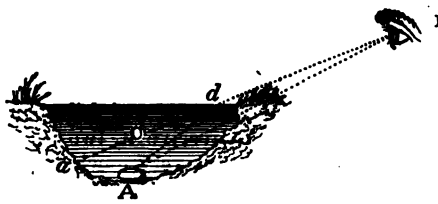


Fig. 5.

were a white stone at the bottom of a pond, an observer at B would perceive its image at C; supposing this line BC to be continued—as by a rod with which we desire to strike the stone—it will fall at *a*. An instructive experiment, is to place a coin in the bottom of a basin, and then retiring so far from it, that the edge of the basin prevents the eye from seeing the coin, request an attendant to pour in water, steadily, without removing the coin; when the fluid rises to a certain height the coin will again become visible. If the line B *a* in the figure represents a stick placed in air and water, it will appear as if broken at *d* from the same cause.

2. If a ray of light falls perpendicularly upon a transparent body, as a plate of glass, (fig. 6,) it passes through, without suffering refraction as the line A *b c* which we suppose to pass through a piece of glass with parallel faces. If, however, a ray B *b* falls at any angle upon the surface it is bent to *d*, and on emerging again into the air, it will be again refracted in a direction *d e* parallel to B *b*.

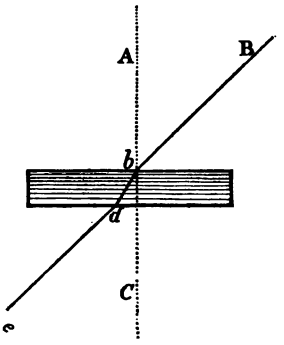


Fig. 6.

3. It will now be understood that a ray of light, while it is passing through a medium of unvarying density, suffers no deviation from a straight line, but that in passing from one medium into another, differing, howsoever slightly, in density, it is bent. The law, being that *when light passes out of a rare into a dense medium the angle of incidence is greater than the angle of refraction; and when light passes out of a dense into a rare medium, the angle of incidence is less than the angle of refraction.* The twilight of our climate is entirely dependent upon the refracting power of the air. The suns sinks below the horizon *a a*, (fig. 7,) but its rays still fall upon the upper regions of the air. They are there bent in upon the next denser stratum of air, and still more so in passing into the next, so that at A the sensation of light is experienced, long after the sun has set, as long, indeed, as the direct rays of the sun can reach that portion of our atmospheric envelope indicated by B in the diagram. Many other remarkable natural phenomena, as mirage, the apparent

elevation of sea-coasts, halos, and the rainbow, are due

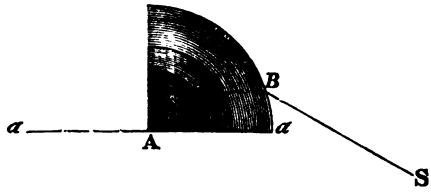


Fig. 7.

to refraction. The production of colour by refraction will form a subject for consideration in a future page.

4. The properties which lenses possess of enlarging any object, as in the glasses of spectacles, of the microscope, or of the telescope, are entirely due to the phenomena of refraction. The consideration, however, of the laws of refraction, from spherical surfaces, belong more especially to that section of our work which we have devoted to optics and optical instruments.

5. Reflexion.—If we look into a silvered-glass, a polished plate of metal, or a pond of still clear water, we see our own image. This is due to *Reflexion*. The radiations, from the surface of the body, illuminated by solar or artificial light, are reflected from the surface upon which these rays fall. But let us examine the condition with a single source of light, such as a taper, A A (fig. 8.) If M M is a mirror of

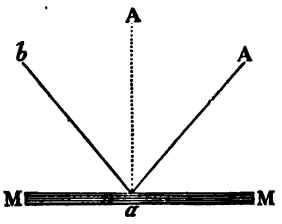


Fig. 8.

any kind, and A is placed so that its rays fall perpendicularly A *a*, they are all reflected back along the same line. If, however, the taper is placed at A, and its rays are incident at the point *a*, they then suffer reflexion to *b*. The eye being placed at *b* would perfectly see the image at A, which, supposing it was a single ray of light admitted through a hole at A, and totally reflected, would not be seen at any other point. The line A *a* is called the *angle of incidence*, and the line *a b* the *angle of reflexion*. We therefore say the *angle of incidence and the angle of reflexion are equal, but on contrary sides of the perpendicular.* Accordingly as we vary the form of the reflecting surface so we alter the size of the reflected image; but the above law of reflexion is equally true for curved as it is for plane surfaces.

6. Under the influences of the laws of reflexion and refraction all the blessings of light which we enjoy are determined. The eye (fig. 9) is a beautifully-constructed

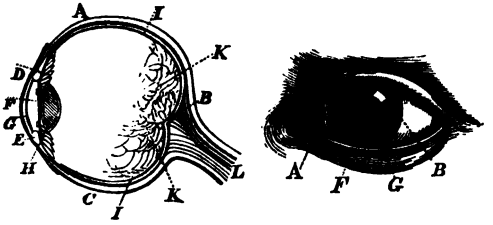


Fig. 9.

refracting instrument, by which the rays from external objects are brought to a focus on a peculiarly-sensitive tablet, on which the images are painted, and upon which, indeed, we *see* them. The eye being merely the instrument into which the mind *looks*, and discovers the objects, by which the individual to whom it belongs, is surrounded. Accordingly as the various surfaces of the organic and inorganic bodies in nature have the power of absorbing, reflecting, and refracting the rays

of light, so are they coloured to our perceptions. There are no substances which possess an innate colour. The colours of flowers, which give so much beauty to the garden, the tints which the dyer produces upon textile fabrics, and the hues which the painter employs to embody on the canvas the conceptions of his genius, are all alike due to a *surface action*, by which some rays are sent to the eye, while others are absorbed.

7. The phenomena of colour now claim our attention. The boy blows his soap bubble, and is delighted to witness, as it floats in the air, the beautiful play of colours upon its surface. A drop of yellow oil, or of spirit varnish falls upon water, and as it spreads upon the surface of the liquid, it passes through a variety of the most intense colours. Thin films of glass, or of mica, give similar colours. Sir Isaac Newton was the first to investigate these chromatic phenomena, and he shows that at certain thicknesses all transparent bodies possess this power of decomposing white light into coloured light, each particular colour, for the same medium, depending upon the thickness of the film.

Fig. 10.

By placing two lenses, as A A', (fig. 10), a plano-convex lens, and *a a'*, a double convex lens together, it is obvious they can only touch at one point, and that around that point the space regularly increases in size. By means of screws, these surfaces can be squeezed closer together, and thus are produced a series of coloured rings dependent on the thicknesses of the film of air: the curvature of the lenses being known, the thickness of the film producing any colour can be determined. The tenuity of these films is so great that their thicknesses can only be reckoned in millionths of an inch. These vary from 1 millionth to 77 millionths.

8. The colours produced by fibres and by grooved

surfaces are the result of analogous conditions. Our space will not allow of our entering into the consideration of these, we therefore proceed to the analysis of a ray of white light by prismatic refraction.

9. If we allow a pencil of sun-light to pass through a small hole into a darkened room, after the manner previously described, and place a triangular piece of glass—which we call a prism—so that the rays fall upon the first surface A B (fig. 11), and emerge at its second

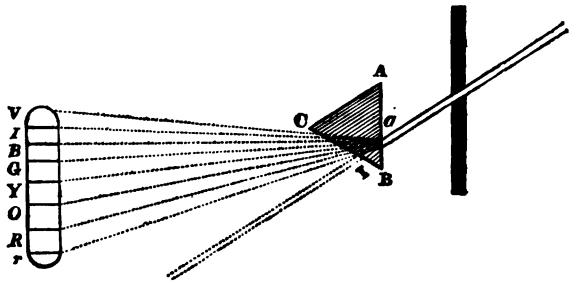


Fig. 11.

surface C I at the same angle, the white beam which fell originally at *a* is altered in direction, or it undergoes refraction, and an oblong coloured figure, which is a distorted image of the sun, is produced upon any screen placed to receive it. This image is called the *solar spectrum*, or the *prismatic spectrum*, and has usually been regarded as consisting of seven rays—*red*, *orange*, *yellow*, *green*, *blue*, *indigo*, and *violet*, indicated in the diagram by the respective initials; *r* or extreme red being added. Sir Isaac Newton conceived that these rays depended upon the angle to which the ray was bent out of its path by the prism, and he conceived that some rays were more susceptible of this deviation than others, *i.e.* that a violet or a blue ray was in a condition to suffer a greater degree of refraction than a red ray or a yellow ray. His expression of the law which

he imagined was a true explanation of the phenomena was to this effect—*a given angle of refrangibility indicates a given colour—a given colour argues a given angle of refrangibility.* There are some reasons, however, for doubting the entire correctness of this Newtonian hypothesis.

10. If we look at the prismatic spectrum through a piece of glass stained blue with the oxide of cobalt, we discover another ray below the ordinary red ray, which is of a very beautiful crimson. This ray is usually termed the extreme red, or the crimson ray. If the spectral image is thrown upon a piece of paper stained with some vegetable yellow, as turmeric, a new ray becomes visible, at the most refracted end, beyond the violet, to which the name of the *lavender ray* is given, although its colour may be regarded as a neutral grey. Modern research has still enlarged the prismatic spectrum. There are several solutions, such as those of sulphate of quinine, of the astringent principle of horse-chestnut bark, or, some of the resinous oils obtained from coal-tar, a green variety of fluor-spar, and a peculiar yellow-glass usually termed Bohemian canary-glass, which possess the remarkable property of *transmitting* either white light, or light coloured in correspondence with the colour of the medium through which it is transmitted, while they disperse from their first surfaces rays of a colour totally different, these being either blue, purple, or green. If the prismatic spectrum is thrown upon these dispersive surfaces, we discover the remarkable fact, that these rays have a much higher degree of refrangibility than any luminous rays with which we were acquainted. They appear beyond the Newtonian spectrum, forming, as it were, a new spectrum, shining with a peculiar phosphorescent light. This peculiar effect has been called *fluorescence*, from the circumstance that fluor-spar exhibits the phenomenon in a striking manner.

11. It will be evident, from this statement, that white light may be decomposed into more than seven

coloured bands. We may now reckon ten or more, which we enumerate, (fig. 12,) commencing with the least refrangible, and proceeding to those of the highest refrangibility.

The crimson ray; red, orange, yellow, green, blue, indigo, violet, lavender; and the fluorescent rays, which are seen as celestial blue, pea-green, or purple.

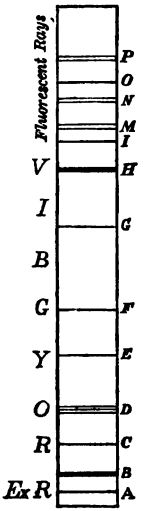


Fig. 12.

12. There is, however, every reason for believing that many of these rays are but combinations of some of the others. It is thought the orange may be due to a mixture of the red and the yellow, that the green band may be produced by the blending of the yellow and the blue. Indeed, Sir David Brewster and some others, consider that white light consists of only three primary rays, red, yellow, and blue, the other rays resulting from the intercombination of these rays. The subject is, however, still under examination. Certain it is that white light consists of several coloured rays —that the coloured rays are manifested by refraction, and that by recombination we can reproduce white light; for if we place a second prism against the face of the first, the rays are recombined, and a white spot of light is produced. Or we may recombine the rays, and thus produce white light by means of a lens. The illuminating powers of these rays are very different; the greatest intensity of light exists in the yellow ray while it diminishes towards either end. Of course *white light* has a greater degree of illuminating power than any one of the coloured rays, since the entire reunion of all the rays is necessary to produce whiteness.

13. If we interrupt any one ray, we produce colour. Thus if we stop the violet rays, the light will become

yellow; or if we interrupt the blue or green rays, we shall produce different tints of redness: on the contrary, if we check the passage of the red, and the other rays at the least refrangible end, we produce every shade of green, blue, and violet. In this way we may imitate every tint in nature, and that, too, with a perfection and brilliancy which cannot be matched by art. If these experiments are tried on a sheet of white paper, they afford a satisfactory explanation of the colour of natural objects, and confirm the truth of Newton's hypothesis, that *the colour of natural bodies are not qualities inherent in the bodies themselves by which they immediately affect our sense, but are mere consequences of that peculiar disposition of the particles of each body, by which it is enabled more copiously to reflect the rays of one particular colour, and to transmit, stifle, or absorb the others.*

14. In producing a very pure prismatic specimen, by means of a perfect glass prism, which decomposes the line of light admitted through a fine slit, some new and curious conditions attract attention. It is then discovered that the chromatic bands forming the spectrum are crossed by a great number of black lines—spaces, in which there is an entire absence of light. These spaces were first observed by Dr. Wollaston, but from their having been carefully examined by Fraunhöfer, of Munich, they are commonly called *Fraunhöfer's dark lines.* In figure 12, a few of the more important dark spaces alone are marked, with the letters attached by which they are designated. The causes which lead to these interruptions in the spectrum are unknown; it is not improbable but they may be referred to the absorption of rays by the medium through which the light passes, in its passage from the sun to the earth.

15. In considering the phenomena of light, the peculiar conditions of *Double Refraction* and *Polarization* must not be omitted.

The *double refraction* of a ray of light, that is, the splitting of it into two rays, takes place when the

medium through which the light passes is of unequal density, or in which the arrangement of the particles constituting the mass is subject to variations. The most remarkable body in nature possessing this power is Iceland spar. Let A B C D fig. 13, represent a crystal of this substance, if L is a ray of light falling upon it, it will within the crystal split into two rays, *l l*, and form two spots of light upon any screen placed to receive them. If instead of this we place the crystal on a piece of paper marked with a black stripe or spot, and look through it, two stripes or spots will be seen; these two images are called the *ordinary* and the *extraordinary* ray: on turning the crystal, one will be seen to revolve around the other. Although Iceland spar possesses this power in a high degree, a great number of bodies have the same power under certain conditions, and amongst others the crystalline lenses of the eyes of most animals are endowed with this property.

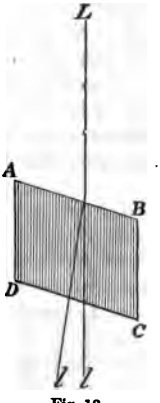


Fig. 13.

16. It is not easy within our prescribed limits to give a clear explanation of the *polarization of light*. An account of its discovery will convey the best impression of some of its phenomena. A French philosopher, M. Malus, was looking at the light of the setting sun reflected from a window in the Luxembourg Palace, through a prism of calcareous spar. He found that when he held the prism in one position he saw the golden rays most perfectly, but that if he turned the prism round through a quarter of a circle, although he continued to see the window, all the light which was previously reflected so brilliantly had disappeared. Upon turning the prism round another 90° the rays passed as freely as before, but upon turning it through another similar space, the rays were again extinguished. The

light was here reflected from the surface of glass in the window at an angle of 56°. Now, if we place a plate of glass at this angle and receive a ray of light upon it, the reflected beam and the transmitted beam will be found to be altered in their conditions. They will have undergone *polarization*.

17. An *ordinary ray* of light will pass through a transparent plate of glass in whatever position it may be placed relative to the incident beam, the *polarized ray* will not pass through it in all positions. An *ordinary ray* is likewise reflected in all positions; from the reflecting-glass a *polarized ray* is not reflected in all positions of the mirror. A *polariscope* (fig. 14), as the instrument is called for producing these conditions, is easily constructed: take two tubes, A and B, the one fitting within the other, and hence capable of revolving; fit on to the end of A a plate of glass not quicksilvered, and capable of turning round so that it may form different angles with the axis of the tube, a similar plate of glass is fixed on to the other tube, B. By an arrangement of this kind the two plates of glass can be placed in any position relative to each other. If we let a pencil of light, L, fall upon the glass A, at an angle of 56° 45′, and let the glass be so placed that the reflected ray will pass along the axis of the tubes and fall

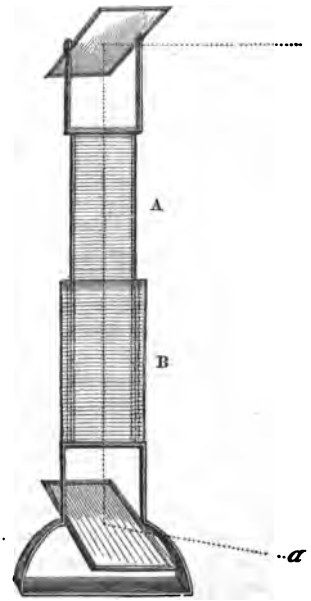


Fig. 14.

on the second plate B, also at an angle of 56° 45′, it will be found on turning this round that there are two positions in which none of the rays are reflected, although in other positions the reflection is more or less perfect. The light has undergone polarization. It is not easy to explain what really takes place; the explanation usually given is of this order. Each ray of common light progresses with two systems of vibration, one wave moving in a horizontal plane, and the other in a vertical plane; the act of polarization is the separation of these two systems from each other, and hence it is that the horizontal wave is only reflected or transmitted in certain positions of the reflecting or the transmitting body, and the same with the vertical wave. Whether this be a correct explanation or not, the phenomena of the polarization of light are amongst the most beautiful with which physical optics has made us acquainted. Spectra, far more intense and beautiful than those produced by ordinary light, are produced, and forms of the most remarkable, but at the same time symmetrical character, mark the path of the polarized rays through transparent bodies.

18. Our knowledge of polarized light enables us to trace out the molecular constitution of transparent bodies, and to determine the lines along which the particles of matter have arranged themselves to form crystals. Numerous practical applications have also been made of the phenomena; the sugar refiner and the cultivator of beet-root for the manufacture of sugar determine, by its aid, problems of much importance to them; the medical man discovers by it conditions of health and disease, which he could not otherwise detect; to the surveyor it becomes the means by which he can calculate the depth of water over a shoal at a safe distance from it; and it enables the astronomer to determine whether the stars are suns, shining with self-emitted light, and to define the luminous conditions of even the Cometary Nebulæ which fly so rapidly across the immensity of space.

LESSON III.

HEAT AND CHEMICAL POWER.

1. HEAT.—The warmth of the solar rays every one must have observed, and experience teaches us that the variations of the seasons are mainly due to the increase and decrease of the heat-rays which are associated with light. If we place a red and a blue glass in the sunshine with delicate thermometers behind them, the highest temperature will be attained by that one on which the rays passing the red media fall. An observation of this sort led Sir W. Herschel to measure the temperature of the prismatic rays. This he did by placing very sensitive thermometers across the coloured rays already described. The experiments made gave the following results:—

In the blue rays		the heat	was	56°
,,	green	,,	,,	58°
,,	yellow	,,	,,	62°
,,	red	,,	,,	72°
Below the red		,,	,,	79°

Therefore it was proved that the greatest heat existed in the least refrangible rays, where they cease to give light.

2. A very pretty experiment by Sir John Herschel shows this in a yet clearer manner. A piece of thin paper, blackened on one side, is placed so that the prismatic spectrum falls on the unblackened side, which is then washed with strong ether. When any body dries unequally it reflects light unequally; the dry parts becoming white, while the wet portions appear gray. The spectrum dries out such an image as that represented. (Fig. 15.) The spot *r* corresponds with a space a little

below the red ray of the spectrum, and the diminishing action of the heating rays is indicated by the elongated cone between *r* and *c*. By this experiment it is proved that heat rays exist yet lower, and the spots *a b c* indicate rays of considerable thermic power, which are scarcely at all refracted by the prism. From this we learn that the maximum points of light and heat in the spectrum are not coincident, and that the refracting powers are widely different.

Fig. 15.

3. We have the power of separating the heat and the light rays from each other by absorbent media. A slice of black mica, or of obsidian, obstructs nearly all the light, but all the heat freely passes; on the contrary, a glass, stained green with oxide of copper, scarcely interferes with the passage of light, but stops nearly all the rays which possess any heating power, and more particularly those which are the least refrangible. Glass slightly tinged green by copper has been employed, at the suggestion of the author of this paper, in glazing the Palm-house in the Royal Botanic Gardens at Kew, for the purpose of preventing the action of the most scorching of the solar rays on the plants, and it has proved eminently successful.

4. CHEMICAL POWER.—If the sun's rays fall upon some preparations of silver, which are white—as the chloride of silver—they change colour, and become nearly black. This power of producing chemical change, or of effecting the decomposition of the metallic salt exposed to solar influence, is one of the most remarkable phenomena which have engaged the investigations of men of science. It cannot be doubted, but that through all time, men must have observed that some colours were bleached, and that others were darkened by the sunshine; but no one appears to have inquired into the phenomena. At length the alchemists observed that the solar rays

changed the colour of some salts of silver. They were then disposed to believe that gold was silver, "pierced through with the sulphurous principle" of the sunbeams, and they believed themselves near the discovery of the principle of transmutation, in search of which they wasted their lives. From this false interpretation of a remarkable fact, no progress was made until about the latter end of the eighteenth century, when a young Swedish chemist discovered that chloride of silver was not blackened equally by all the rays. Scheele's experiments and observations were repeated and confirmed; it was proved that all the least refrangible rays—the red, orange, and yellow rays—produced no change in the colour of this salt, but that the most refrangible—the blue, violet, and rays beyond this space,—were most chemically active.

5. If a paper covered with chloride of silver is exposed to the action of the prismatic spectrum, it begins to darken in the blue ray, and the darkening extends with rapidity to the end of the violet; it is continued some considerable space beyond the spectrum where there is no light. By long exposure the red ray effects a slight chemical change, but the extreme red ray produces none. There are two or three points which must be remembered. By the diffused light which is always present, when such an experiment as this is made, the paper is tinted over every part but two spaces, one where there is the most heat *a*, and the other where there is the most light *b*, are preserved absolutely white and unchanged; the greatest change taking place at *c*. These three dissimilar maxima will be best understood by the following diagram, (fig. 17,) where the three curved lines represent respectively the variations of intensity,

Fig. 16.

and the maxima of luminous power L, of heating power H, and of chemical action C. As we can separate light and heat from each other, so can we exhibit the luminous and the chemical forces apart. If we take a solution of the yellow bichromate of potash, we shall find that no chemical rays permeate it, although the light

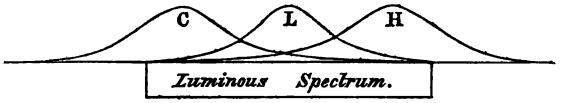


Fig. 17.

shines through it with much brilliancy; and chloride of silver, placed in full sunshine behind such a transparent medium, undergoes no change. But if we take a deep purple solution of sulphate of copper and ammonia, although scarcely any light passes it, we shall discover that chloride of silver will blacken as readily behind it, as if it was exposed to the full sunshine,—because the chemical rays pass it freely.

6. It is yet to be decided whether those three principles are modified forms of one, or whether they are dissimilar agents united in the sunbeam. We have three very distinct phenomena; these are *light*, *heat*, and this chemical power, to the cause of which the term *actinism* has been applied. This last power or principle is that by which is produced all the variety of pictures grouped under the general term of *photographic drawings*. Pictures are obtained upon silver plates, on glass, and on paper, and for their production a preparation known as the iodide of silver, is usually employed. The pictures are obtained in two ways—first, by placing the leaves of plants, engravings, or anything else which we desire to copy on the prepared surface, pressing them close with a plate of glass, and exposing directly to the sunshine, when all the exposed parts darken, leaving the spaces covered unchanged, or only changed in proportion to the

quantity of light which penetrates the superposed body; or second, by the use of the camera obscura. The images of external objects falling on the prepared surface, produce a change exactly proportional to the quantity of chemical radiations proceeding from the external object. These pictures are then developed or exalted by the application of some chemical compound, possessing the required power, and fixed or rendered permanent by employing another chemical material, which has the power of dissolving all the silver salt which remains unchanged.

7. PHOSPHORESCENCE.—This term is applied to the emission of light from any body, under peculiar circumstances. The whiting, and some other fish, speedily assume this condition. Many varieties of decayed wood, in like manner, glow in the dark. Phosphorus, combining with the oxygen of the air, undergoing indeed slow combustion, shines brilliantly in the dark, hence the term phosphorescence. There are two substances, combinations of sulphur and lime or barytes—known as Canton's and Baldwin's phosphorus; which being exposed to the sunshine, and then carried into a dark room, give out a considerable quantity of light. This appears to show something like the absorption of the solar rays, and their subsequent emission. Yet it is curious that the effect is due to those rays of the spectrum which possess the least illuminating power. If either of these solar phosphori, when smeared over paper, be exposed to the action of the prismatic spectrum, it will be found that they only become luminous upon the spaces covered by those rays which are most chemically active—all the other parts continuing perfectly dark. This proves either that the chemical rays excite this phosphorescent power, or that it is due to those extra-spectral luminous rays, which have been described as becoming visible in sulphate of quinine solution, or in uranium glass. We know the conditions by which the phenomenon can be brought about, but the cause producing it is involved in mystery, notwith-

standing the long and earnest investigations which have been made from time to time by the most eminent scientific observers.

8. NATURE OF LIGHT.—The excitement producing vision is explained, by one of the two theories of light, which we have avoided mentioning until the chief phenomena of this agent had been described. Sir Isaac Newton supposed light to be an emission of infinitely fine particles of matter from the sun, these particles travelling at the enormous rate of more than 190,000 miles in a second of time. In consequence of this velocity, notwithstanding the particles are supposed to be 1000 miles apart, they appear as a continuous stream. Matter was supposed to exert certain forces, by which the eye was protected from injury by the beating of light upon its membranes, or passing through its lenses, and the phenomena of colour, &c., were explained upon the hypothesis of variations in the rates of progression.

9. The undulatory theory, as it is termed, supposes all space to be filled with a peculiar attenuated medium called *ether*, which interpenetrates even the most solid masses of matter. When, by the action of some force, this is put in motion, such motion being a system of waves or undulations, light is the result.

Colour, as exhibited by the prismatic spectrum, this theory supposes to be due to different lengths in the wave, and variations as to the number of undulations in a given time.

Beyond this, according to the undulatory theory, a certain amount of wave-motion is supposed to produce *heat*. This being increased, *light* is the result; and eventually, the vibrations still increasing, the power of producing *chemical* change is obtained.

10. Most luminous phenomena can be explained upon either theory; but the conditions of the polarization of light are more satisfactorily elucidated by the hypothesis of undulations.

11. The consideration of the action of the principles, heat, light, and chemical power, involved in the solar

beam in producing the great phenomena of creation, opens a wide and interesting field of inquiry. The first spring of life in the germination of the seed has been proved to be due to the chemical power of the sunbeam; the growth of the plant and the formation of wood to the light; and the process of flowering and the perfection of the fruit to the solar heat rays. The animal, like the vegetable economy, depends for its very existence on light. Before its creation the world was a chaos: but God said, Let there be light: and organization, life, and beauty at once overspread the face of the earth.

ROBERT HUNT.

Biography.

KEPLER, WITH NOTICES OF COPERNICUS AND TYCHO BRAHE.

BY HUGO REID.

1. ASTRONOMY, the most sublime, is also the most ancient of the sciences, and has been cultivated from the earliest ages. The heavenly bodies are everywhere conspicuous, and naturally attract the attention: many of their changes of position are obvious, and must have been observed even by the rudest tribes; some of these changes would soon be found to coincide with the changes of the seasons, and they would, therefore, be watched more carefully and studied, on account of their importance for the division of time and the regulation of agricultural operations. Eclipses and comets astonished the terrified nations, and, sometimes preceding or coinciding with great events, were supposed to indicate important changes amongst the affairs of men—wars, victories, the birth or death of illustrious

persons. The positions of the planets, to each of which a peculiar character was ascribed, were also supposed to have an important influence on terrestrial events; and hence the real science of astronomy soon became associated with astrology, the pretended art of predicting events from the phenomena of the heavenly bodies.

2. Astronomy is generally believed to have been first studied by the nations of the east; and it has been said that astronomical observations were made and recorded at Babylon, so far back as the year 2234 B.C. Certain it is, that at a very early period, as shown by their accurate knowledge of the length of the year and of other astronomical periods, the Chaldeans, Egyptians, Indians, and Chinese, must have had a considerable knowledge of many astronomical phenomena, only to be acquired by long-continued and careful observations. Not only were these amongst the first civilized nations, but their geographical position was peculiarly favourable for astronomical study. The clear sky of these southern climes gives a beauty and brilliancy to the heavens, unknown in our foggy, northern regions; while several of the most striking of the stars and constellations, seldom or never seen in our high latitudes, rise above the horizon of those who inhabit the more favoured regions of the south.

3. Accordingly, astronomy did make great progress in ancient times. The most successful cultivators were HIPPARCHUS and PTOLEMY, both of the famous school of Alexandria, who flourished, the first about 150 years before, the latter about 140 years after, the commencement of the Christian era. After the time of Ptolemy, the fall of the Roman Empire and the dark ages intervened, and the science of astronomy made little progress for about 1400 years; when, in the sixteenth and seventeenth centuries, it made very great advances, chiefly by the genius and labours of five illustrious men—COPERNICUS, TYCHO BRAHE, GALILEO, KEPLER, and NEWTON.

4. Nicolas Kopernik, or Copernicus, was born at Niom in the east of Russia, in 1473. He studied at the university of Cracow, and subsequently at Bologna and at Rome, in the latter of which cities he became professor of mathematics. Latterly he accepted an ecclesiastical office in the cathedral of Warmia in his native land, and devoted himself chiefly to study, living a quiet and peaceful life. He died in 1543, a few days after the completion of the printing of his great work, 'On the Revolutions of the Celestial Orbs.' By long-continued study he had come to the conviction that the *Pythagorean* system of astronomy, which supposed the sun to be fixed, the earth and other planets to revolve round it, and the earth also to rotate daily, was better adapted to explain the phenomena than the *Ptolemaic* system; in which the earth was supposed fixed, and the heavens to revolve round it daily—the opinion then adopted by philosophers as well as by the people generally. Since the publication of the work of Copernicus, the former theory has rapidly gained ground, and is now universally adopted.

5. Tycho Brahe, the celebrated astronomer, whose labours prepared the way for the great discoveries of Kepler, was born in 1546, of a noble family, on the estate of his ancestors, near Helsingborg, in Sweden, opposite Elsinore. He studied at the university of Copenhagen, and while there his attention was turned to astronomy, by the occurrence of an eclipse of the sun, predicted to take place on the 21st of August 1560. Its occurrence at the time, and to the extent predicted, deeply interested him, and he longed to be acquainted with a science which imparted to its votaries the power of foreseeing future events. His friends sent him to Leipsic to study jurisprudence; but he secretly studied astronomy with arithmetic and geometry, and the construction and use of astronomical instruments, that he might be able to understand, and himself perform, the observations and calculations by which astronomical phenomena were predicted.

Inheriting a fortune by the death of an uncle, he gave up the profession of the law, and returned to Denmark, where he was upbraided and ridiculed by his friends, for applying himself to such degrading pursuits as making astronomical observations; and finding himself unpleasantly situated, entered upon a tour through Germany.

6. At Augsburg, having met with some superior instrument-makers, he had a quadrant made sufficiently large to show single minutes of a degree, and also a large sextant, with which he made many observations. He returned to Denmark in 1571, prosecuted the art of alchemy with the view of obtaining means for pursuing his favourite study; and in 1573 published a work on a bright new star which had suddenly appeared in the preceding year in the constellation Cassiopeia, and finally disappeared in 1574. It is singular that Tycho at first refused to publish his observations, thinking that it would be derogatory to the dignity of a nobleman: such was the estimation in which science was held in those times. He did not consider it, however, beneath his dignity to marry a peasant girl of his native village. He again travelled through Germany, and was about to take up his abode at Basle, when the King of Denmark induced him to settle in his dominions, giving him a liberal pension, granting him the small island of Huen south of the Sound, and about fourteen miles from Copenhagen, and erecting there a splendid observatory, which was called Uranibourg, or the *city of the heavens*. There he spent twenty years, carrying on a series of the most important astronomical observations on the motions of the sun, moon, and planets, determining with care the places of the fixed stars, &c.

7. Tycho and Uranibourg became famous, and were visited by eminent men of science and princes; among the latter of whom was James VI. of Scotland, (I. of England) who spent eight days at Uranibourg, when he went to be married to Anne, the sister of the King

of Denmark. Tycho's friend, Frederick II., died in 1588, and his successor, Christian IV. was persuaded by nobles, who were envious of Tycho's fame and pension, and by physicians, who were jealous of him for his successful and gratuitous practice of their art—to withdraw the public grants in his favour. Unable to support the establishment at Huen from his own resources, he withdrew from it in 1597, and ultimately settled at Prague, where the Emperor Rudolph allowed him a pension and gave him a residence and observatory, to which he brought his instruments from Huen. There he continued his astronomical observations, and died in 1601 in the fifty-fifth year of his age. Tycho Brahe made several important astronomical discoveries, but did greatest service to the science by the number of accurate and carefully-recorded observations he made on the heavenly bodies, which proved of the greatest value in the hands of his successors. From observations of a comet which appeared in 1577, he showed that it was beyond the moon's orbit and could not be merely a meteor in the atmosphere, an opinion which was much contested, particularly as opposed to the then prevalent idea that the heavenly bodies were carried round, attached to solid crystalline spheres. He did not adopt the Copernican system, nor the Ptolemaic; but devised one of an intermediate character, sometimes termed the *Tychonic*. He supposed the moon and sun to revolve round the earth as their centre, while the planets revolved round the sun. For a long time he believed in astrology, and having calculated the nativity of the Emperor Rudolph, predicted that an attempt would be made on his life by his relations; but he is said to have renounced astrology towards the end of his life. He was keen in the pursuit of alchemy, and was in some respects very superstitious. If, on any expedition, he met with an old woman or a hare, he returned immediately. At Uranibourg he kept an idiot, called Lep, who, he believed, had at times the power of predict-

ing future events. These were weaknesses or follies of the age in which he lived. Notwithstanding these, Tycho was a great man, and by his genius and unwearied industry conferred great benefits on the human race.

JOHN KEPLER.

8. JOHN KEPLER, whose name, in *Kepler's Laws*, is inseparably linked with the science of Astromony, was a German,—a member of that highly intellectual race that gave us printing and the Reformation, and has continued to enrich mankind by so many great contributions to literature and the arts and sciences. He was born at Weïl, in Wirtemburg, in the year 1571, being about twenty-five years younger than Tycho Brahe, and seven years younger than Galileo, his illustrious contemporaries: he followed close upon Copernicus, and prepared the way for Newton. Kepler belonged to a poor, but noble family, and was educated first at the school of Maulbroun, then at the university of Inbingen, where

he made great progress in mathematics and philosophy, and acquired such a reputation that at the early age of twenty-three years, and although he had not previously made astronomy the subject of special study, he was appointed professor of that science at Gratz in Styria. He applied himself with ardour to his duties, but was far from being contented with teaching what was already known and established. His active, inquiring, and imaginative mind sought to discover the relations and causes of the various phenomena brought before him. "There were three things in particular," he says, "of which I pertinaciously sought the causes why they are not other than they are—the number, the size, and the motion of the orbits."

9. This is highly characteristic of Kepler: he longed to know the reasons why there were so many planets, and no more; why they were at such distances and not at other distances, and so on; and above all, he was pertinacious: if he tried one mode of explanation and found it would not answer, he at once gave it up and sought another, and he was not discouraged by many repeated failures. He pertinaciously went on with new conjectures or guesses, then tried their fitness by the most laborious calculations; and by thus trying in succession every relation that occurred to his well-informed and speculative mind, he at last arrived at the discovery of great truths. But this guessing, or hypothetical method, sometimes led him into serious errors, as in his first astronomical work, entitled 'Mysterium Cosmographicum,' published in 1596. He had first supposed one of the orbits might be double, triple, or some multiple of the other, and endeavoured, unsuccessfully, to find some relation of that nature between them. He also tried if any such relation could be established if a new planet were inserted between Mars and Jupiter, and another between Mercury and Venus, both of which he supposed invisible on account of their smallness; but even this would not give any numerical or geometrical relation. At last he hit upon the idea of representing the magni-

tudes of the orbits by spheres, having the five regular solids inscribed within them or surrounding them. The magnitudes and distances of these spheres, he found to coincide nearly with those of the orbits of the planets. But this was a merely fanciful analogy and accidental coincidence, having no foundation in reason. On the discovery of Jupiter's satellites by Galileo, he "fell to thinking how there could be any addition to the number of the planets without overturning my 'Mysterium Cosmographicum' published thirteen years ago, according to which Euclid's five regular solids do not allow more than six planets round the sun." Soon, however, he found some way of reconciling them, and longed for a telescope to anticipate Galileo, if possible, in discovering two round Mars (as the proportion seemed to him to require six or eight round Saturn, and perhaps one each round Mercury and Venus).

10. In consequence of troubles between the Catholics and Protestants at Gratz, Kepler, who was a Protestant, gave up his professorship there in 1599, and was appointed assistant and then successor to Tycho Brahe as imperial mathematician at Prague. They engaged in drawing up a new set of astronomical tables from Tycho's observations, to be called Rudolphical, in honour of the emperor. Though a considerable salary was attached to his office, it was irregularly paid, and was often far in arrear, in consequence of the expensive war then going on. Hence Kepler was often much straitened for means, and to assist himself, was obliged to have recourse to astrology, and calculated nativities with the view of augmenting his income. He had published a work entitled 'Principles of Astrology,' in which he denounced what he considered the impositions of ordinary astrology, and endeavoured to show the true principles of the science, in which he believed to a certain extent. In 1609 Kepler published his 'New Astronomy, or Commentaries on the Motions of Mars.' This is his great work, and contains two of the discoveries which are usually called 'Kepler's Laws.'

11. From the earliest period up to the time of Kepler, it had been supposed that the orbits of the planets were *circles*, and that they moved in these orbits at a *uniform* rate, that is, always passing over the same distance in the same time, not going greater sometimes and slower at other times. Even Copernicus entertained these ideas, and his system, simple as it was in other respects, was encumbered with various complications to adjust it to the established principle of uniform motions in circular orbits. The ancients, with that admiration of the perfect and the beautiful which distinguished them, attached peculiar virtues to that simple and elegant figure, the circle; and, viewing it as a perfect figure, and the heavenly bodies as perfect, unchangeable, and incorruptible, assumed at once that the celestial motions must be performed in *circles*, and that they must also be *uniform*. So long as nothing was known, of the sun, moon, and planets, than that they moved from west to east through the heavens, their revolutions were easily explained; each moved round the earth in a circle and at a uniform rate. But astronomical observations could not have been carried on for any considerable time with tolerable accuracy, without the remarkable truths being discovered that the sun, moon, and planets do not move at a uniform rate through the heavens, but sometimes slower, sometimes quicker, and that the planets sometimes stand still for a time, and even occasionally go back for a little in a direction opposite to their previous course. How were these appearances to be reconciled with uniform motion in circular orbits? They were reconciled by very ingenious and complex mathematical theories; one, the theory of *epicycles*, said to have been devised by Apollonius, a celebrated geometrician, to explain the apparent irregularities in the movements of the *planets*, the other the *excentric* theory, devised by the famous astronomer Hipparchus, to explain the irregularities in the *sun's* yearly course. By the system of epicycles it was supposed that each planet revolved uniformly in a

small circle (epicycle), the centre of which moved uniformly in a circle in the centre of which the earth was placed. By the excentric theory the earth was supposed not to be in the centre of the circular orbit in which the sun was believed to move uniformly. Thus the apparently irregular courses of the sun and planets were explained on the principle of uniform circular motions, which was adhered to as a fundamental point. But great complexity was thereby introduced into the astronomical system, from which even that of Copernicus was not free. To this Milton alludes in the following well-known lines:—

> "When they come to model Heaven,
> And calculate the stars, how they will wield
> The mighty frame!—how build, unbuild, contrive
> To save appearances!—how gird the sphere
> With centric and excentric scribbled o'er,
> Cycle and epicycle, orb in orb."

12. To this system of gratuitous assumptions and intricate figures and movements, to escape from the difficulties arising from these assumptions, Kepler put an end. It had weighed as an incubus on astronomy for hundreds of years. He first showed that the planets did not move in circles, and that their motions were not uniform. And all the phenomena are explained at once by the simple substitution of the oval or ellipse for the circle, and of an unequal rate of motion, but quickened or retarded at regular times, for the assumed uniform motion. Kepler showed that the planet moves in an ellipse with the sun in one focus—his *first law;* and that the planet moves more rapidly as it is nearer to the sun, so that an imaginary line from the planet to the sun (radius vector) passes over equal spaces in equal times—his *second law.* These great principles were established mainly by examining carefully the astronomical observations of Mars left by Tycho. He first ascertained them of Mars, and subsequently of the other planets. His *third law*, that the squares of the periods of the planets are in proportion to the cubes of

their mean distances from the sun, was discovered in 1618, and published in the following year, in a remarkable work entitled 'The Harmonies of the World.' These are Kepler's celebrated "laws," which at once overthrew vast and intricate systems under which astronomical science had been buried for ages; and proved the foundation on which Newton raised his magnificent structure of the true science of astronomy.

13. Kepler was for some time professor of mathematics at Linz in Austria, and finally settled in a professorship at Rostock, under the patronage of the Dukes of Mecklenburg and Friedland, the latter of whom was a great patron of astrology. He died in 1630, in the sixtieth year of his age. He was twice married, and has left a very amusing account of his search for a second wife, in which he employed a number of his friends to assist him. He wrote many works on philosophical subjects, as optics, gauging, an epitome of the Copernican system, &c.; and in these are to be found original remarks and suggestions, which were of great value to future discoverers. He had many ingenious and correct ideas on the nature of gravity, and on various points in optical science. Few men have conferred greater benefits on science. He was not a man of the highest genius, being certainly much inferior in intellectual power to Galileo and Newton. But he had an ardent inquiring spirit, a keen desire to penetrate into the mysteries of the universe, a lively fancy and great acuteness; these, aided by industry and indomitable perseverance, enabled him to benefit mankind by discoveries of the greatest value.

HUGO REID.

Astronomy.

BY ROBERT MAIN.

SIGNS OF THE ZODIAC, THE SEASONS, ETC.

1. In the preceding lessons in Astronomy it has been attempted, first, to give a notion of the simpler principles of the science as they may be understood by any person of ordinary intelligence who studies the phenomena of the heavens with the naked eye; secondly, to explain briefly the vast additions to our knowledge which have been acquired by the use of the telescope; and thirdly, to give an idea of the lunar and solar orbits, of the nature of eclipses arising from the conjunctions and oppositions of the sun and moon, and of various phenomena which are of very great use in the determination of terrestrial longitudes, and in different branches of nautical science.

2. In the present lesson it is intended to supply explanations of such phenomena as require for their elucidation a tolerably accurate knowledge of the motions of the heavenly bodies, and which, though of great and prominent interest and importance, could not be so well discussed till the student had acquired a tolerably correct idea of the general principles of the science.

These are chiefly, the grouping of the stars in constellations; the seasons of the year; the phases of the moon and of the inferior planets; and, lastly, the apparent motions of the planets as seen from the earth.

It has been mentioned in a preceding lesson (First Reading Book, page 363), that the ancients, for convenience, supposed the whole circle of the ecliptic to be divided into twelve equal parts of thirty degrees each, and that these distinct portions were called the *Signs of the Zodiac*.

These signs of the zodiac corresponding to the commencement of each of its divisions are as follows:—

♈ Aries; ♉ Taurus; ♊ Gemini; ♋ Cancer; ♌ Leo; ♍ Virgo; ♎ Libra; ♏ Scorpio; ♐ Sagittarius; ♑ Capricornus; ♒ Aquarius; ♓ Pisces.

These, it is necessary for the reader to be acquainted with, since they are used in many astronomical treatises; though in the practice of modern astronomy it is better to disregard altogether the zodiac and its divisions, which are only historically valuable, as recalling those early periods of the world when language itself was conducted in a great measure by means of symbols.

3. The ecliptic, or plane, in which the sun's motion is performed, affords a more natural plane of reference for the positions of the planets than the equator, which only defines the direction of the earth's rotation, though the observed places both of planets and stars must of necessity be primarily referred to this latter plane. If through the centre of the visible sphere we draw a line at right angles to the ecliptic, it will cut the surface of the sphere in two points, called the poles of the ecliptic, and the distance of a body from the first point of Aries, measured along the ecliptic, is called its *longitude*, while its distance from the ecliptic, measured in the arc of a great circle passing through the poles, is called its *latitude*.

4. The bright stars of the heavens, referred to the ecliptic by their longitudes and latitudes, were, from the most ancient times, divided into constellations or asterisms, and these constellations have had their boundaries determined generally by some fanciful resemblance which the outline of the included group of stars bore to the demigods and heroes of antiquity, and to animals. The following is a list of them as they were given by the Greek astronomer, Hipparchus, who flourished about 140 years before Christ. He was the first astronomer who compiled a catalogue of the fixed stars with their observed latitudes and longitudes. This catalogue is preserved in the *Almagest* of Ptolemy,

and is one of the most valuable of the records of ancient astronomy.

5. He divided the heavens into three portions—the northern, the zodiacal, and the southern portion.

The northern constellations, twenty-one in number, are: Ursa Minor, Ursa Major, Draco, Cepheus, Bootis, Corona Borealis, Hercules, Lyra, Cygnus, Cassiopeia, Perseus, Auriga, Ophiuchus (or Serpentarius), Serpens, Sagitta, Aquila, Delphinus, Equuleus, Pegasus, Andromeda, and Triangulum.

The zodiacal constellations are twelve in number. Their names are identical with those of the signs of the zodiac. The zodiac itself is a band extending a few degrees on each side of the ecliptic, so as to include the excursions of all the larger planets from that plane.

The southern constellations, fifteen in number, are: Cetus (the Whale), Orion, Eridanus, Lepus (the Hare), Canis Major (the Great Dog), Canis Minor (the Little Dog), Argo, Hydra, Crater (the Cup), Corvus (the Crow), Centaurus, Lupus (the Wolf), Ara (the Altar), Corona Australis (the Southern Crown), Piscis Australis (the Southern Fish). To these constellations many others have been added by modern astronomers, but they concern chiefly the advanced student or the professional astronomer. By comparing diligently the heavens with a good map at different seasons of the year, a familiarity will be soon gained with the relative positions of the principal constellations and of the chief stars in each.

6. In connection with the motion of the sun in the ecliptic, it will be desirable to illustrate the nature of the seasons of the years, and this will be best done by diagrams adapted separately to places within the arctic-circles and the tropics.

Let H O represent the horizon of any place within the northern arctic circle, P *p* the earth's axis, E Q the equator, S *s*, H *s'*, *s''* *s''*, diurnal circles described by the sun at different periods of the year. Then it is evident that as long as the sun's declination is less than

E H or P Z, that is the colatitude, he will rise and set every day, the length of the day constantly increasing as he goes from southern to northern declination; when, however, the southern declination is greater than the colatitude (and it must be so during a certain portion of the year, because Z P or O Q is less than the *obliquity*), he never rises; and, on the contrary, when the northern declination is greater than Z P or E H he never sets. It becomes an easy problem to determine the limits of time during which the latter phenomena take place, and also the length of any day during the intermediate period.

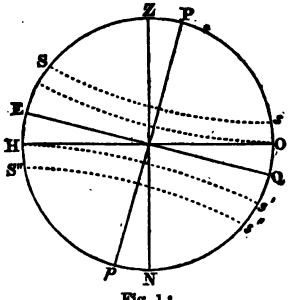


Fig. 1.

Again, for a place within the tropics, bearing in mind that the altitude of the pole is equal to the latitude of the place, let P*p* be the axis of the earth.

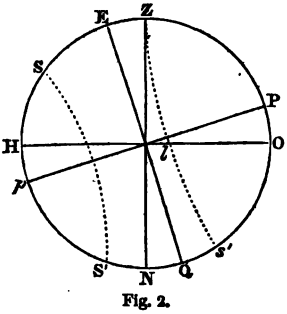


Fig. 2.

Then must P O or E Z be less than the obliquity, that is, less than 23° 27½′. The sun will, therefore, after attaining to north declination, pass over the zenith Z, his diurnal course being represented by the dotted line *z l s'*. Also, if E S represent his extreme southern declination, S Z will represent his greatest meridian zenith distance, and is plainly equal to the latitude added to the obliquity.

For a place in the equator, the sun will, in his diurnal course, describe vertical circles perpendicular to the meridian, and his greatest north and south meridian zenith distances will be each equal to the obliquity.

It is evident also from this diagram, that, for all periods of the year, the sun will be during half his diurnal course above the horizon, and during the other half below it, or, in other words, the days and nights will be equal throughout the year.

For places situated in either of the temperate zones, the sun will rise and set during every period of diurnal revolution, that is, for a certain portion of the twenty-four hours constituting the solar day, he will be above the horizon, and for the remaining portion he will be below it. The exact length of the day and of the night at any period of the year (except at the vernal and autumnal equinoxes, when the days and nights are equal for all places throughout the globe), depends on the latitude of the place, and can be calculated for any particular day. Thus, we find in our almanacs the time sun rise, and sun set, given for every day in the year for the latitude of London. The inequality in the lengths of the days and the nights, is greatest for places near the arctic circle, and least for places near the equator; the days being longest for places in the northern hemisphere at the summer solstice or mid-summer, and shortest at the winter solstice or midwinter. For places in the southern hemisphere the conditions are reversed, the days being longest in December, and shortest in June.

7. The seasons admit also of a more popular and elementary explanation as follows:—

The earth revolves round the sun in the plane of the ecliptic, in such a way as to keep its axis of diurnal rotation always parallel to itself. Imagine it now in the position which it occupies at the vernal equinox, when the line of intersection of the ecliptic and equator passes through the centre of the sun. In this case it is evident that the unlightened hemisphere of the earth is determined by the plane drawn through its centre at right angles to the line joining it with the sun, and that the axis of rotation will necessarily lie in this plane, since it is at right angles to the line of intersec-

tion of the ecliptic and equator, that is, to the line passing through the sun. Hence, a place in any parallel on the earth's surface being carried round by the diurnal rotation, will be an equal number of hours in light and in darkness, or in other words, the days and nights are equal throughout the globe. The same explanation will apply to the autumnal and vernal equinoxes.

At the summer solstice, however, the axis of rotation preserving its parallelism, the plane passing through it and the sun is at right angles to the ecliptic, and the angle between the axis and the line joining the earth and sun produced is equal to its inclination to the ecliptic. Therefore, the plane determining the boundaries of light and darkness, which is at right angles to the joining line, is inclined to the axis at an angle equal to the obliquity, and meets the surface of the earth at the arctic and antarctic circles. Hence, any place within the northern arctic circle will be illuminated during the whole time of rotation, as the sun will not set; while to any place in the antarctic circle he will not be above the horizon during a whole diurnal rotation. Also for any place in the northern hemisphere the illuminated portion of the parallel of latitude will be greater than the unilluminated, or the days will be longer than the nights; while to any place in the southern hemisphere the nights will be longer than the days.

At the winter solstice the conditions are reversed, the arctic zone being in darkness, and the antarctic zone fully illuminated; while, for places in the northern hemisphere, the days are shorter than the nights, and for places in the southern hemisphere the days are longer than the nights.

8. The heavens present us yet with other objects besides those which have thus far occupied our attention. Of these, the moon and planets are the chief, comets visible to the naked eye being of rare occurrence. Let us begin with the body which is apparently nearest to us, and which contributes so essentially to our comfort and convenience, namely, the MOON (fig. 3).

A very little study of her motions and appearance would convince us of the following facts; firstly, that

Fig. 3.

she has a rapid motion from west to east; secondly, that this rapid motion is accompanied by a visible change of figure; and, thirdly, that after a certain period denominated a month she returns to nearly the same part of the heavens, and that all her changes are resumed in the same order.

The change of figure, too, is evidently connected with her position relatively to the sun, for if we begin to watch her when she appears as a fine crescent in the west immediately after sunset, and continue our observations on succeeding evenings, we find that as her angular distance from the sun increases, her illuminated disk becomes larger, and that when she passes the

meridian of our place of observation about midnight, or is opposite to the sun, she is sensibly full.

After this time she *wanes*, and becomes still smaller as she rises later every evening, going still from west to east, till she is seen as a slender crescent a little before sunrise in the morning. In all cases, too, we see that she turns her illuminated disk towards the sun, so that, when she sets soon after the sun, in the west, her western limb is illuminated, and when she rises before the sun in the east, her eastern limb is illuminated. If, also, we were to trace out her path nightly throughout a lunation, on a celestial globe, by means of the stars near which she is observed to pass, we should find that she describes a great circle in the heavens inclined at a very small angle to the ecliptic, and, combining this with the fact that her variation of apparent diameter is small, we should conclude that she describes in the order of the signs of the zodiac a nearly circular orbit round the earth. Her distance, too, on account of the rapidity of her angular motion, cannot be great, and is probably incomparably smaller than that of the sun, whose angular motion is scarcely one-twelfth part of her motion.

9. Now, by means of these facts, her *phases* can be very accurately accounted for, on the supposition that she is an opaque body, deriving from the sun the light which she exhibits to us.

Let E be the earth, and M_1, M_2, M_3, &c., positions of the moon in her orbit during one revolution; we will also suppose the sun to be stationary, as our object is only to explain the general phenomenon of the phases. We will, for the same reason, suppose her to move in the ecliptic in the same plane as that in which the sun moves; indeed, she never deviates from it more than $5\frac{1}{2}°$. The sun's distance being then very great in comparison with that of the moon, we may suppose also that his light falls always in the direction s E, and that it therefore falls on the moon in directions opposite to the arrow points in the figure. Lines perpendicular to these

directions will represent the projections on the ecliptic of the illuminated surface; while lines perpendicular to the radii E M_1, E M_2, &c., will represent the projections of the surfaces visible from the earth. The angle formed by these two lines will therefore measure the part of the illuminated surface which is visible from the earth.

Thus at M_1 the moon is immediately between the earth

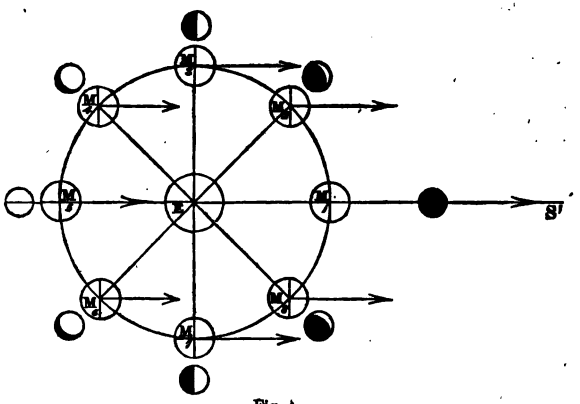


Fig. 4.

and the sun, or in *conjunction* with the sun. The illuminated surface is, therefore, exactly opposite to that visible from the earth, and we have the case corresponding to the *change of the moon*. There would indeed be an eclipse of the sun at every revolution, if the moon moved exactly in the plane of the ecliptic, as will be evident on inspection of the figure, and the wisdom of the Creator is therefore evident in having caused her orbit to be slightly inclined to that plane. At M_5, on the contrary, the whole of the illuminated surface is opposite to the earth, and then is *full moon*. In this position the moon is said to be in *opposition*. At M_3 and M_7 the projections of the illuminated and the visible surface are inclined to each other at half a right angle, and the

moon is one-quarter full. At M_3 and M_7 these lines are at right angles, and the moon is half-full, or *dichotomized*. Finally at M_4 and M_8 the lines, measured always in the same directions, are inclined at three-fourths of two right angles, and the moon is three-fourths full. It must, however, be remembered that from M_1 to M_5 the illuminated disk is increasing, and from M_5 to M_1, during the remainder of the lunation, it is decreasing, or the moon is waning.

10. The points M_3 and M_7, when the moon is *dichotomized*, afford means for roughly determining the ratio of the distances of the sun and moon from the earth, and in this way it was actually determined by Aristarchus of Samos, in the early ages of Grecian astronomy. In the accompanying triangle let, for example, E, S, and M be the relative positions of the earth, the sun, and the moon. Then, from the explanation of the phases which has preceded, it is plain that S M and E M must be at right angles to each other (the moon being half-full). If, then, we can measure the angle M E S, or the angular distance between the sun and moon, the solution of the right-angled triangle will furnish us with the proportion of the distances E S and E M, or of the distances of the earth and moon from the earth.

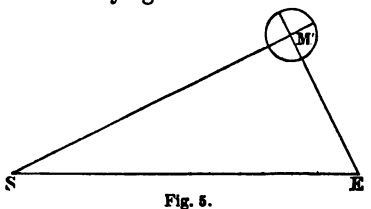


Fig. 5.

On account of the imperfections of the instruments for measuring angular distances in use at this early period, this method gave a very erroneous result, the distance of the sun from the earth being found by Aristarchus to be about twenty times that of the moon, whereas it has since been proved to be about 400 times. The right-angled triangle, in fact, from having one of its sides so very small compared with the others, is what is called an *ill-conditioned* triangle, so that a very small error in the measure of the angle makes a very large

error in the deduced ratio of the distances. In addition to this, it is very difficult to determine the exact time at which the moon is *dichotomized*. This is a good illustration of the use of methods which, though apparently good in theory, fail altogether in practice.

11. If we look at the moon in her first quarter in the spring season, we shall observe a phenomenon which affords an interesting proof that that portion of the surface which is generally invisible when not illuminated, does still exist. The whole circle of the moon is at such seasons distinctly visible, the portion not illuminated by the sun being, however, very faint compared with the remaining portion. This is supposed to be due to the light reflected back again from the earth to the moon, since, with regard to the moon, the earth's surface is almost fully illuminated, and, from its size, must cast a considerable light upon her. The phenomenon is known by the name of *earthshine*.

By tracing on a globe the positions of the moon throughout a whole revolution, we should ascertain that she moves in a great circle, cutting the ecliptic in two points, very nearly at the opposite extremities of a diameter. These points are called the *nodes* of the lunar orbit.

12. Next to the moon, the most remarkable object visible to the naked eye is the planet Venus. Every one is acquainted with this beautiful planet, under the title either of the *morning* or the *evening star*. At certain times she will be seen shining with moderate brilliancy in the west soon after sunset, and will then be observed, while increasing in splendour, to separate farther and farther from the sun till she arrives at a kind of stationary point in the heavens. Soon after this she goes back to meet the sun, and her retrograde motion increasing with great rapidity, she is soon lost to view. She will then be seen before the rising of the sun and separating farther from him, while her brilliancy constantly decreases, and, after a considerable time, will return to meet that luminary again, when she becomes for a second time an

evening star, and the cycle of her changes is renewed in the same order.

13. These motions seem sufficiently complicated, and we can scarcely wonder that, in the early ages of astronomy, erroneous theories were formed to explain them. The two great errors of ancient astronomy, the stumbling-block, in fact, which prevented a just conception of the leading features of the solar system, were, first, the supposition of the immobility of the earth, and, secondly, the hypothesis that it, and not the sun, is the centre of the whole system. These errors did not involve then those absurd consequences which are evident to us, who have been able to measure the distances and to calculate the masses of the sun and planets; and in a rapid survey of the heavens, where only such leading facts are to be dwelt upon as can be elucidated by mere inspection with the unassisted eye, they need not be dwelt upon. We could prove immediately, by mapping down the places of Venus, that she does not move in a great circle, and therefore does not revolve round the earth, and we should thus naturally assume that she revolves, most probably, round the sun. Her great brightness, and her rapid changes of position as well as of brilliancy, prove that she not only comes occasionally near to the earth, but that she is sometimes much nearer than at others. Finally, since she never separates from the sun beyond a certain distance, it becomes evident that her orbit is within that of the earth, or she is an *inferior* planet.

14. We will now show how her stationary and retrograde motions, and her oscillations on each side of the sun, can be explained, on the supposition that she describes an orbit nearly circular within that of the earth, which latter is also assumed to be a circle described round the sun.

Let the outer circle in the figure represent a section of the sphere of the heavens; *a b c d* and A B C D the orbits of Venus and the earth round the sun S.

Then if *a* and A, *b* and B, be simultaneous positions

of the planet and the earth, and we join A *a* and B *b*, these lines, when produced, will give the positions 1 and 2 for the apparent places of Venus in the heavens when seen from the earth. Venus will, therefore, appear to have moved in the order of the signs, or with *direct* motion. At or near *b*, B *b* will be a tangent to the orbit of Venus,

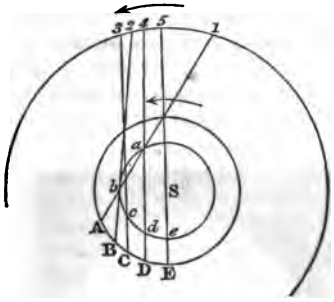


Fig. 6.

and if the earth were stationary she would be moving in a direct line towards the earth, or would be stationary. But as the earth moves forward, this motion will give an apparent motion to Venus, still *direct*. At this point, however, she has her greatest elongation from the sun, which is measured by the angle *b* B S. Soon after this, at some point, for instance *c*, when the motions of both the planets resolved perpendicularly to *c* C are equal, she will not appear to have any motion, or she will be *stationary* at 3. She will now retrograde in describing the arc *c d*, and will come into *inferior* conjunction with the sun when she is at *e*, immediately between that luminary and the earth at E, still continuing her retrograde motion past conjunction, when she becomes a morning star.

We might follow up her motions till she again came into conjunction with the sun at *superior conjunction*, that is, on that side of the sun farthest from the earth; but the student will be able to do this for himself. This general rule, however, may be given for the motions of inferior planets; *they retrograde before and after inferior conjunction, but move directly in the remaining parts of their orbits.*

Besides Venus, there is another inferior planet,

Mercury; but this planet is rarely seen with the naked eye, his orbit being within that of Venus, and his extreme elongations never amounting to much more than an hour on each side of the sun.

15. The superior planets visible by the unassisted eye —that is, the planets whose nearly circular orbits lie outside that of the earth—are Mars (fig. 7), Jupiter, and Saturn; their retrogradations and stationary points admit of a somewhat similar explanation to those of the inferior planets, though from the fact of their motions being performed in a circle larger than the orbit of the earth, it will be easily seen that their elongations may have any degrees of magnitude from 0° to 180°; and that, therefore, they come frequently by the motion of the earth into *opposition* with the sun, that is, that the difference of the longitudes of the sun and planet will amount to 180°.

VIEW OF MARS.

Fig. 7.

The superior planets will be found to *move directly before and after conjunction with the sun, and to retrograde before and after opposition.* The physical peculiarities of these interesting planets have been dwelt on in the treating of the wonders which the telescope reveals to us; but any person looking towards the eastern portion of the sky at the present season (December, 1856) will easily recognise Saturn by his superior brilliancy; while Jupiter, long past opposition, is seen shining with steady splendour, vindicating his title as the chief of the planetary bodies.

16. Occasionally the public attention is excited by the appearance of a *comet* visible to the naked eye. These bodies are known to obey the same laws of planetary

movement observed by the other bodies of the solar system, but their appearance and their physical constitution are widely different. Those visible to the unassisted eye are generally attended by a luminous appendage called a *tail*, or train, consisting of transparent matter through which the stars are visible. This tail branches off from the head or *nucleus* of the comet on both sides, and the part of the phenomenon immediately surrounding the nucleus is called the *envelope*, or *coma*. They differ in every possible respect from each other in length of tail, brilliancy, and form of orbit. Some are attended with a train extending over a considerable portion of the heavens, like the Great Comet of 1843. Others, like that of 1853, are attended by a short tail of only a few degrees in length, while the greater number are visible only by powerful telescopes. Some again return after a few years, moving in orbits considerably more excentric than the planets, yet still of moderate excentricity, like the comets of Encke and Biela; but the greater number of them, after receding from us, never appear again, moving in very long ellipses occupying several hundreds or thousands of years in their description.

17. Thus wonderful, even on the cursory examination which can be given them by means of the unassisted eye, are the principal facts and objects connected with the starry heavens. The sun, rising and setting with undeviating regularity, yet varying our seasons so as to give us our seedtime and our harvest, our summer and our winter—the former with its exuberant richness of foliage and produce, the latter with its stillness and repose needful for the teeming soil; the moon giving us her beneficial light throughout the whole year, yet giving it most when most needed, in the long winter nights; the stars, glittering in the firmament in apparently an inextricable mass, yet capable of being classified and arranged with admirable precision; the planets, sometimes moving forwards, sometimes backwards, sometimes standing fixed in the heavens, yet all pursuing

their simple and orderly march in the eternal circuits ordained for them by the Creator; and, lastly, those mysterious visitors, the *cometary* bodies, startling us from time to time by their sudden and fiery appearance, and then again as suddenly vanishing from our sight;—these are subjects affording ample scope for meditation to the pious and philosophical inquirer, even when considered without reference to those infinitely greater wonders which the telescope reveals. All tell in well-understood language of the great God who made them and us; whose infinite power made them and gave them motion with an energy which we cannot comprehend; whose infinite wisdom arrayed them with an exquisite order which we cannot fathom; and yet, whose boundless love made them all subservient to the welfare and convenience of us, the least of his creatures, and the inhabitants of one of the smallest of his worlds.

ROBERT MAIN.

Biography.

LESSON I.

LIFE OF GALILEO.

BY HUGO REID.

1. GALILEO DE GALILEI, commonly called GALILEO, was born at Pisa in Tuscany, on the 15th of February, 1564. He made many brilliant discoveries in astronomy, having been the first who explored the heavens with the aid of a telescope: he laid the foundation of the science of mechanics; he wrote several admirable philosophical works, which contributed greatly to free the human mind from serious errors and faulty modes of reasoning; and he is especially celebrated for upholding and establishing the Copernican doctrine, that it is the earth which turns round daily, and not the heavens.

2. Little is known of Galileo's childhood. He is said to have given marked indications of a lively, active, and intelligent turn of mind, and to have been very fond of constructing models and little pieces of machinery, a striking point of resemblance between him and his great successor, *Newton*. During his youth he acquired the rudiments of classical learning and such other knowledge as the times afforded. He possessed considerable talents for music and drawing, both of which he cultivated with some success. His genius for painting, and the skill he had acquired in it were such that at one time he thought of devoting himself to it as a profession. Music continued to be a favourite recreation with him during his maturer years.

3. While a student at the university of Pisa, Galileo made an important discovery in *dynamics*. Happening, when in the cathedral, to cast his eye on a large lamp suspended from the roof, and which was swinging backwards and forwards, he noticed that the swingings (vibrations or oscillations, as they are usually termed) were performed in equal times; that is, the lamp always occupied the same time in passing from its highest position on one side to its highest position on the other; and that this was the case whether the vibrations were great or small, that is, whether the lamp swung violently and far, or gently and only a short distance. He tested the accuracy of his observation by comparison with the beatings of his pulse; and when he became assured that the times of vibration really were equal, he proposed the application of the discovery to ascertain the rate of the pulse, thus reversing the operation by which he had first satisfied himself of the truth of his observation. He found that the movement of the pendulum was quicker as its length was shorter; and perceived its value as a measure of time. This simple instrument has proved of the greatest value to astronomers, and, through them, to mankind. It is the great time-keeper for common life, and has been of assistance in determining the laws of motion. It led to the knowledge of

the fact that the force of gravity is different at different parts of the earth's surface; and thus aided in determining the true figure of the earth.

4. Galileo's taste for music and drawing, and his desire to understand their principles thoroughly, led him to the study of mathematics; this determined his subsequent career. He was so delighted with the new field of ideas thus thrown open to him, that he prosecuted the study with a degree of zeal and enthusiasm which alarmed his father, who had designed him for the medical profession. His passion for mathematical and physical science, however, proved such, that his father prudently permitted him to follow the bent of his genius. Studying Archimedes, after he had mastered Euclid, he wrote treatises on the *Hydrostatical Balance*, and on the *Centre of Gravity*, which brought him into notice; and in 1589, in his 26th year, he was appointed Professor of Mathematics in the university of his native city, Pisa.

5. Galileo was now in a position which enabled him to speak with effect. He quickly detected many of the errors in which the prevailing systems of mechanics abounded: and it was not long ere he obtained a signal triumph over the upholders of the old philosophy. It had been asserted by Aristotle, and was considered as an established fact in mechanics, that falling bodies fall faster in proportion as they are heavier. It was supposed that a weight of ten pounds and a weight of one pound, being let fall from the same height at the same moment, the ten pounds weight would reach the ground in one-tenth of the time which the one pound weight would occupy in falling. The arguments on which this notion was founded appeared to Galileo so fallacious that he doubted it; and on reflection, and the performance of some simple experiments, he came to the conclusion that bodies of different weights fall in the same time, with a very slight difference, caused by the resistance of the air. The defenders of the Aristotelian philosophy were not convinced, and ridiculed his ideas on the subject. Galileo appealed from argu-

ment to experiment, ascended the celebrated leaning tower of Pisa, and from the summit of that singular structure, in the presence of his opponents, dropped bodies of different weights at the same moment. We may conceive the keen anxiety with which the descending bodies were watched, and the mortification of the philosophers of the old school when the triumph of Galileo was completed by the fall of the bodies at the same moment. Still they were not convinced; and amongst other objections, remarked that the heavier body does fall a very little before the other. This was owing, as Galileo himself explained, to the resistance of the air. But, though he was successful in establishing more correct views on various points — this success gave offence to many of his colleagues, who could not be persuaded that what they had always looked upon as settled principles, could be utterly erroneous; perhaps Galileo himself was rather impetuous, and did not make sufficient allowance for the difficulties that everyone feels in abandoning old convictions. At all events, from these and some other causes, he soon found himself so unpleasantly situated in Pisa, that in 1592 he was glad to accept the professorship of mathematics in the university of Padua.

6. In the year 1609, when in Venice, Galileo heard that an instrument had been invented by a Dutch spectacle-maker, which represented distant objects as nearer than they really were, and therefore larger. This, he himself tells us, is all he heard of the subject; and upon applying his mind to consider how such an effect could be brought about, his knowledge of optics, his ingenuity, and mechanical skill enabled him to plan and construct a *telescope* (or far-seeing instrument). Whoever was the inventor, now for the first time was this powerful means of astronomical discovery in the hands of a man of science and learning, great observing powers, an original genius, and highly philosophic spirit, not wedded to old-established ideas, but keen and ardent in the pursuit of truth. The

invention excited the greatest interest at Venice where Galileo first made it known; for upwards of a month his time was almost entirely occupied in showing it to the principal inhabitants; and on a hint from the Doge he presented the instrument to the senate, who doubled his salary and confirmed him for life in his professorship at Padua.

7. When the novelty was over and the excitement had in some degree subsided, Galileo commenced a survey of the heavens. On observing the planet Jupiter with his telescope, on the 7th of January, 1610, he was much struck by the appearance of three small stars near him, not visible to the naked eye, and almost in a line with the planet, two to the east, and one west of him. What was his surprise, on turning the telescope towards Jupiter on the following evening to find that the two had moved to the other side of the planet, and that the three were now on his west side! Watching them carefully, night after night, he observed that they regularly changed their positions in relation to Jupiter, but still kept near him, as if they moved round him. On the 13th, a fourth came into view. After long and careful examination of their motions, finding that they never departed far from Jupiter, and were in continual motion near him, disappearing on one side and reappearing on the other, he came to the conclusion that these four little stars were attendants, satellites, or *moons*, which revolve round Jupiter, and follow him in the same way as our attendant, the moon, moves round and follows the earth. To distinguish them, he named them the *Medicean* stars, in honour of the *Medici* family, his patrons. This great discovery was made known to the world in a small work, entitled, *Nuncius Sidereus*, or the messenger from the stars, published about the end of March, 1610.

8. Perhaps no work ever published created such a sensation. People wondered, just as we should wonder now, if it were reported that inhabitants had been discovered in the moon. Some said doggedly, that such

things were not and could not be; one argued that as the new planets were invisible to the naked eye, they could not exert any influence over the earth, therefore were useless, and therefore did not exist. And the principal professor of philosophy at Padua laboured with logical arguments to persuade the Grand Duke of the absurdity of the alleged discovery; and, afraid lest he himself should be convinced against his will, actually refused to look through the telescope at them. Others thought they would disparage Galileo as an astronomical observer, and acquire fame for themselves, by finding out a few more satellites for Jupiter: one reckoned *five*, another *nine*, and gave them names in honour of their sovereigns; but a short time deprived them of their honours. Jupiter soon moved away from those fixed stars which had been supposed to be the additional satellites, carrying with him only the four which Galileo had originally pointed out.

9. By means of the telescope, he also made the important discoveries — that the fixed stars remain brilliant sparkling points, only brighter than they appear to the naked eye, while the planets expand into broad, opaque, well-defined discs; that there are great numbers of fixed stars, invisible to the naked eye; that the surface of the moon is rugged and unequal, like that of the earth, with high mountains and deep valleys; that the planet Venus exhibits *phases*, as the moon does, showing that she does not shine by her own light, but by reflecting that of the sun; that there are spots on the sun; that the planet Saturn has some peculiar appendages attached to it (afterwards discovered, by means of more powerful telescopes, to be the remarkable rings which surround that body); and several other important and interesting discoveries.

10. It may be doubted whether any causes, not even excepting Galileo's own celebrated "Dialogues," contributed so powerfully as these great discoveries, to subvert the Ptolemaic and establish the Copernican system of Astronomy. According to the former,

which was the prevalent system at that time, the earth was a fixed body, placed in or near the centre of the universe, dull and dark, gross, corrupt, and changeable; the heavens turned daily round the earth, and were pure, and unchangeable, and opposite to the earth in every respect, the stars and planets being *perfect* bodies, and shining by their own light. According to the new or Copernican theory, the sun was the fixed centre of the universe, the earth turned daily on its axis, and moved yearly round the sun, the other planets also described orbits round that luminary, and resembled the earth, having no light of their own, but shining by reflecting the light they received from the sun. Now, the expansion of the planets into broad opaque discs when viewed through the telescope, showed that they had a substance or body, that they were, probably, much nearer to the earth than the fixed stars, and by assigning to the planets a substance or body, the mind was naturally led to the resemblance between them and the earth, which the Copernicans maintained. The system of Jupiter and his satellites did much to pave the way for the adoption of the system of Copernicus. It was a solar system in miniature. As the sun was viewed as a centre round which the planets revolve in regular periods at various distances, so, here was an analogy in Jupiter with his four moons at different distances and each with its own period. As the earth was believed by the Copernicans not to be the centre and sole object of creation, so here was Jupiter shown to be of very considerable magnitude and of sufficient importance to have no less than four moons attending on himself. This splendid planet with its attendants proclaimed the comparative insignificance of our earth, which had been fancied to be the sole end and aim of creation; while it was proved at the same time not to be the sole centre of motion in the universe. Also, the existence of phases in the planet Venus, was a powerful argument in favour of the new system. It at once showed that that planet did not shine from its own light, but from

borrowed or reflected light; and that she revolved round the sun and received her light from him, as the form and magnitude of the illumined part were such as would be caused by her revolution round the sun. Here were grounds for, at least, a strong presumption that Venus revolved round the sun, and a striking analogy between that planet and the earth, not shining by its own light.

LESSON II.

LIFE OF GALILEO—*continued.*

1. THE astronomical discoveries of Galileo are the best known, and it is with these that his name is most usually associated; but he also made great discoveries in the science of mechanics, of one part of which (dynamics) he may indeed be viewed as the founder. He published a small treatise on Mechanical Science in 1592, and in 1636 his celebrated *Dialogues on Motion*, which he himself is said to have considered as his best work. He had much difficulty in getting it printed, in consequence of his name having been placed in the list of authors whose works were prohibited. It was at last printed at Amsterdam, by Elzevir, the celebrated printer in that city.

2. In this he first laid down distinctly and illustrated the principle of "virtual velocities," often termed the *golden rule* of Mechanics. Seeing the wonderful effects of machines, as a lever or a pulley, in enabling a person of no great strength to move vast weights, many ingenious persons have wasted much time and means in projects for procuring a great force by the expenditure of a very small power. Galileo showed that moving a great weight easily by the help of a machine, is like dividing the weight into a number of fragments and carrying these pieces one by one until at length we have removed the whole weight. This great principle applies equally to the lever, the

pulley, the inclined plane, in every form or combination, and to the hydrostatic press, by which young mechanicians have sometimes projected the procuring of forces of stupendous power.

3. Galileo was the first who pointed out the true cause of the acceleration of a falling body; that while (disregarding the resistance of the air) the motion imparted at first to the falling body continues undiminished, it is receiving fresh accessions of moving force by the continued action of the force which set it in motion—the earth's attraction. He also determined the rate of acceleration; that the spaces described by a falling body are in proportion to the squares of the times; and that the space a body falls through in any time is exactly half of what it would fall through in the same time, if falling uniformly with the velocity last acquired. He also made another great addition to our knowledge of dynamics; he determined the path of a projectile, that is, of a body thrown horizontally or upwards, as a stone, a ball from a cannon, an arrow, a jet of liquid. He showed that the curve described by the projectile must be that particular conic section called a *parabola*. This he deduced from mathematical reasoning from his previous discovery that the spaces described by a falling body are in proportion to the squares of the times.

4. These great discoveries, with those formerly alluded to, namely, the Pendulum, and the fact that, disregarding the resistance of the air, light and heavy bodies fall at the same rate, give Galileo the title to be viewed as the founder of the science of Dynamics; a department of Natural Philosophy, which, besides its important applications to mechanics and the military art, is of inestimable value, as the basis of the great science of Astronomy.

5. Galileo threw out the conjecture that light does not pass instantaneously from place to place, but occupies time in transmission; afterwards established by Roemer, by the phenomena of the eclipses of the satellites of

Jupiter, which Galileo himself had discovered. He says of the sun, "Who can assure us that he is not in the horizon before his rays reach our sight?" His most celebrated work is his "Dialogue on the Ptolemaic and Copernican Systems of Astronomy."

6. There is reason to believe that he had, at an early period, become a convert to the Copernican system; certainly, previous to the year 1597, by which time, as appears from a letter he wrote to his celebrated contemporary, KEPLER, he had fully adopted the opinion of the earth's motion. He first came publicly forward in favour of the Copernican theory in a letter to the Abbé Castelli, in 1613, in which he endeavoured to combat the idea that expressions in the scriptures, relating to astronomical phenomena, were designed to expound any particular system, and held that the Ptolemaic system was as incompatible with a strict interpretation of the language of the Bible, as the Copernican. Being attacked on account of these opinions, he defended and explained them in a long letter addressed to Christina, Duchess of Tuscany. These letters were the beginning of his troubles with the Inquisition; the attention of that court was drawn to his opinions on the subject in 1615; and early in the following year, it declared formally against the Copernican doctrine, and forbid the promulgating or teaching it. To quote the exact words, as recited in the sentence upon him in 1633, he was denounced "for holding as true a false doctrine taught by many, namely, that the sun is immoveable in the centre of the world, and that the earth moves, and also with a diurnal motion; also for having pupils, whom he instructed in the same opinions."

7. We hear little of Galileo for some time in connection with the forbidden doctrines. He visited Rome in 1624, and endeavoured to procure some relaxation of the decree against the Copernican System, but without success. Still he could not rest. He firmly believed it to be the true system, and could not remain content while appearing to sanction a great system of error.

With the ardour of genius he desired to spread the truth, and dispel darkness from men's minds. He set himself to his astronomical work, finished it in 1630, and, after many delays, and much anxiety and trouble, by the aid of a little manœuvring with the censors of the press at Rome, and at Florence, it was printed and published at the latter city towards the end of the year 1632. It consisted chiefly of discussions on the two systems; all the usual arguments on both sides being fully and fairly stated, while great stress is laid on those founded on his own numerous astronomical discoveries. Galileo professed to consider it not as an exposition and defence of the Copernican System, but merely as a view of what might be said on both sides of the question, without pronouncing a positive opinion in favour of either side—as if he were a person quite indifferent as to which opinion might be the true one, and were only describing the argument as a matter of curiosity. But this could not save him: it was seen at once that the Copernicans had always the best of the argument, and, although no judgment was pronounced, that the effect of the work was entirely in favour of the new doctrine. Further, it happened unfortunately that Galileo had made Simplicio, the upholder of the Ptolemaic theory, bring forward some arguments which the Pope (Urban) had formerly urged in controversy with Galileo; the Ptolemaist is represented as being generally confuted and ridiculed: and the enemies of Galileo contrived to make Urban believe that it was he whom the writer designed to turn to ridicule in the character of Simplicio. There is no reason to suppose that Galileo had any such intention; but his enemies had access to the Pope, and contrived to insinuate this idea into his mind.

8. It could not be expected that the powerful Roman Catholic Church would quietly submit to have her decrees violated and turned to ridicule; she had taken her ground in 1616, and Galileo's pretences of merely discussing the question and of implicit obedience were of no avail. The work was, in reality, strongly

in favour of the forbidden system; and the church felt that her authority must be maintained, that so glaring a violation of it could not be allowed to pass with impunity. Galileo was summoned to Rome, to appear in person before the Inquisition. The Tuscan Ambassador at Rome remonstrated, representing the age of Galileo, the broken-down state of his health, and the annoyances of quarantine (a contagious disease being then prevalent in Tuscany). But the court was inexorable; time would be allowed, and quarantine regulations relaxed; but he must be examined in person before the Roman Inquisition. Accordingly, exhausted by infirmities, and the fatigues of his journey, Galileo arrived at Rome on the 14th of February, 1633, and took up his abode at the residence of the Tuscan Ambassador, who seems to have been very friendly to him, and very active in his behalf during the whole of the proceedings. In the beginning of April, he was removed to the office of the Inquisition, lodged in the apartments of one of the officers, and allowed what, considering the character and power of that dread court, must be regarded as a considerable degree of freedom. But he became uneasy and irritated at the tedious progress of his case, and at being within the walls of the Inquisition, and suffered much from illness. On the last day of April, he was permitted to return to the house of his friend, the Ambassador. On the 22nd of June he received his sentence. The venerable sage and philosopher was conducted in a penitential dress to the convent of Minerva, where judgment was passed upon him, in a long and tedious sentence, by the court of cardinals and other prelates who were there assembled.

9. Clothed in the dress of a penitent, on his knees before his weak, fallible, and ignorant judges, the venerable Galileo—the light and ornament of his age—was compelled to repeat a form of abjuration which had been prepared for him, and to renounce the doctrines which he had had the glory of devoting his life to establish. It is said that, as he rose from his

knees, he stamped on the ground, and whispered to a friend, "It *does* move though."

10. Galileo was then taken to an apartment in the residence of one of the officers, but was detained there only three or four days. As the plague was still raging in Tuscany, he was not sent to Florence, but to Sienna, where he was kept in strict seclusion in the palace of the Archbishop till the close of the year, when he was permitted to return to his villa at Arcetri, near Florence. He was placed, however, under considerable restrictions, not being allowed to leave his house without special permission, and few being allowed to visit him. There he spent the remainder of his days.

11. Galileo was now settled at last — we may almost say, confined, at his villa at Arcetri. This seclusion, and several severe afflictions which befel him, embittered the remainder of his days. In 1634, his favourite daughter, Maria, said to have been a woman of extraordinary talent, died, and he was deprived of this great solace of his declining years. In 1637 he became totally blind. Of this misfortune he writes:— "Alas! your dear friend and servant Galileo has become totally and irreparably blind, so that this heaven, this earth, this universe, which with wonderful observations I had enlarged a hundred and a thousand times beyond the belief of bygone ages, henceforward for me is shrunk into the narrow space which I myself fill in it! So it pleases God: it shall therefore please me also."

12. Towards the latter years of his life, the regulations of the Inquisition were somewhat relaxed, and his friends were allowed to visit him more freely. The famous names of GASSENDI and MILTON are among the distinguished strangers who came to see the venerable philosopher. VIVIANI, afterwards a celebrated mathematician, and known as "the last pupil of Galileo," lived with him during the last years of his life; and the famous TORRICELLI joined the circle in 1641. But age, sorrow, and disease were producing their usual

effects; and Galileo's end was approaching: latterly, deafness was added to his afflictions; but his active mind continued vigorous to the last. While making arrangements with Torricelli for a continuation of his "Dialogues on Motion," he was seized with a fatal illness, and died on the 8th of January, 1642, in the 78th year of his age. The Inquisition at first disputed his right of making a will or of being buried in consecrated ground, but withdrew its opposition. His remains were deposited in an obscure corner of the church of Santa Croce in Florence; but the Pope would not permit a monument to be erected to his memory, although a large sum was subscribed for the purpose. Thirty years afterwards a small monumental tablet was erected; and in 1737 a splendid monument was erected over the remains of Galileo and his faithful pupil, Viviani.

And so ends the story of him whom a great poet describes as

"The starry Galileo, with his woes."

HUGO REID.

——— He took his ardent flight
Through the blue infinite; and every star
Which the clear concave of a winter's night
Pours on the eye, or astronomic tube,
Far-stretching, snatches from the dark abyss,
Or such as farther in successive skies
To fancy shine alone, at his approach
Blazed into suns, the living centre each
Of an harmonious system; all combined,
And ruled unerring by that single power
Which draws the stone projected to the ground.

Navigation.

BY JOHN RIDDLE.

LESSON I.

COMMERCE—SHIPS—MEN.

Commerce—its aids—its duty.—The Sailor, his capital and his character.—Ships.—The Captain as he should be.

1. THE power and dignity of a kingdom depend upon the industry and character of its people; and whatever tends to the increase of useful labour, and the elevation of morality, is a proper object of cultivation and nurture by the rulers of the land.

2. Commerce, one of the vital principles of the strength of a nation, recommends itself in an especial degree to the care of an enlightened government, whether we view it as developing all material resources, the incalculable riches of hidden mineral wealth, and those which teem upon the cultivated surface of the

ground, and temper with generous blessings our destiny of toil; or, taking higher ground, as demanding the exercise of the greatest energy and highest intelligence of a people.

Amongst the direct aids which it receives, are the establishment of lighthouses and light-vessels and buoys in properly-chosen situations; the making of charts marked with all the details relating to the depths of water, the currents, rocks, shoals, and sands, and the leading marks for avoiding danger, and for guiding the mariner in the selection of the best channels by which to approach or leave his port; the establishment of harbours of refuge, as well as the devising and sustaining of proper police regulations with respect to lights and signals for avoiding collisions, which are so often attended with distressing loss of life.

3. These are amongst the direct aids to commerce through the sister art of navigation; it is also assisted by judicious systems of taxation and by wise laws for the encouragement of useful inventions, the protection of property and the general maintenance of order, and by the direction of our utmost energies to the promotion and preservation of international peace and goodwill. It is not to be wondered at that the history of civilization should nevertheless show, that the immediate interference of governments with productive labour, or with the buying and selling of the products of manufactures, proves often unsuccessful, and sometimes decidedly mischievous, for this is only one of the infinite variety of instances in which human thought and human action exhibit in their effects that narrow selfishness, the germ of which is never absent from the dealings of men. Commerce itself is widely open to such accusations as this, and it were well that makers and buyers and sellers would always remember the good maxim that "honesty is the best policy," the neglect of which too often changes the fair field of honourable competition into one of robbery, adulteration, and all other phases of cheating and wrong-doing. But let us

not accuse the good for the evil with which the avarice and bad passions of man will mingle it.

4. There is yet another of the brighter phases of commerce to be spoken of; it is one of the principal agents for converting all sorts of capital into income; a process which is deeply interesting to everyone; for everyone has capital and desires income. The capital of the sailor is his muscular strength, his sobriety, his honesty, his alacrity, and his obedience; and these he converts, by the aid of commerce, into clothes and food for himself and his family.

If he be distinguished by more than a usual share of good qualities, although it may not immediately follow that they secure to him a larger monthly payment for his services, they will insure him more steady employment, and he will have an additional reward in the respect which he will command amongst his officers and his shipmates, and the special gratification which only honest men can feel when doing their duty.

5. The sailor is an illustration of the principles of trade and commerce all the more apt to the purpose of this writing, because, firstly, the capital which he brings into the labour market is available by all men who possess the blessings of health and strength, which are maintained and increased by the other qualities of sobriety, activity, diligence, and honesty, and these are amongst the richest gifts held out to men in the open hand of God; and he who refuses them is justly punished even here, by poverty, by disregard, and in the savage feelings and rottenness of heart, which distinguish their absence and render miserable him who disdains them.

Secondly, because in the great ocean-population of this country lies the source of its power as a maritime and commercial nation; and it is of much importance to know what are the qualities to be encouraged and fostered in its hardy sons.

And, thirdly, he is the noblest illustration I can find, because he represents navigation, which in its widest aspect may be called the lusty handmaid of commerce,

the bearer of many burdens, the richest spoils of distant lands; spreading far and wide the benign and civilizing influences of the arts of peace; and whilst opening up the dim pathways of the sea, teaching us in its very wanderings a warmer and deeper love of home by the comforts which it pours into our lap.

And, fourthly, because it is my especial intention to attempt to exhibit the nature, machinery, requirements, and duties of this wonderful art of navigation.

6. Everyone remembers the first recorded instance of a vessel built expressly for floating on the water, that huge ship made by Noah and his sons, with the explicit directions of the Almighty, to save a remnant of the wicked family of man from the death which is most incident to mariners. What a picture is this ship! drifting on the dreadful sea, in its strength and inexorable justice, a type of the wrath of offended deity, whilst below, in the stillness of death, lies all the pride of earth.

Leaving this dismal scene of more than four thousand years ago, but never to forget its awful teachings of the justice of God and the depravity of man, what do we behold in our own time? a forest of masts and fleets of ships in our docks and on the sea.

7. A merchant-ship is a machine for aiding the operations of commerce, by carrying its burdens between countries widely separated, and between which the great waters make a neutral and common highway for all nations. The magnitude of some of these vessels enables the merchant to send large stores of goods, with more convenience and at much less cost than by land carriage, even where this is possible; considering, for example, our own insular position, but more still, the division of men into various hostile families, and, again, the absence of available roads even in many so-called civilized countries.

8. A ship in itself offers to the thoughtful mind food enough for contemplation to occupy its attention much longer than can be permitted to it here. It contains

within itself a history and minute illustration of human industry; specimens of almost all the arts and sciences which distinguish the age of its construction; in which the mathematician, the manufacturer, and the artisan have combined their various powers, and shown in their union the secret springs of our great social compact, our mutual dependence, which furnishes us with the politic, apart from the Christian, argument in favour of contentment with our lot.

Another interesting feature in this matter is the assistance given by ships to ship-building; whence come the timber, the iron, the copper, the cordage, and how many water-carriages have these materials to submit to, before they find their proper relative positions in the constitution of a ship.

9. If the only desiderata in ship-building were economy of material and capacity, then geometry would immediately furnish the necessary conditions of the construction—and the ugly rotundity which they impress upon the little trading ships is everywhere seen disfiguring our ports. If speed combined with safety be more especially desired, mechanics and direct experience must be consulted and our vessels purified, from the grosser elements of our worldly cares and needs, assume more agreeable forms, and assimilate more and more the graceful curves which abound in the works of nature.

10. Or when, as is usually the case, the various qualities of stability, speed, capacity, and an abode for men are to be combined in the proportions dictated by the special services which the ship is destined to perform—then, man in his humble way, and at a great distance, imitates the perfection of creation in adapting the materials at his disposal to the ends he has in view. Sheathing her in metal to protect her timbers against the fierce attacks of the persevering and destructive marine worms—the *Teredo navalis*, the *Limnoria terebrans*, the *Chelura terebrans*—which would speedily destroy them; calling in the aid of the chemist, deeply

learned in the secret powers of nature, to assist still further in protecting the immersed parts of the vessel

Common Barnacle. *Pentalasmis anatifera.*

from the attachments of barnacles, corallines, and the prolific vegetation of the ocean, which impede the motion of the vessel, and bid defiance to the nice calculations of the builder. Let us suppose all fairly accomplished, and that we have now a gallant ship, A 1 at Lloyd's, a willing and obedient slave to all our wishes, only waiting for her master; and then, as sailors say, ready to do all but speak.

11. Who is to be her master? It would be difficult to exaggerate the responsibilities of the master of a large ship which has to traverse the wide ocean, laden not only with the precious gifts of earth, but with the trusting souls of his fellow-men, who rely on his skill and experience, under Divine providence, for the safe issue of their voyage. Many a noble expedition, both on land and sea, has been rendered fruitless from the want of some element in the temper of its leader. Our captain should be a man of many resources, well qualified to select his assistants and to employ their several talents to the best advantage—temperate, of great firmness, courage, and presence of mind, in the imminent perils to which, in the natural course of events, he will be exposed in

his calling. Commanding his men without violence of manner or of language, by the force of the moral influence which his own self-command and self-reliance will inspire, provided these be honestly founded on sound practical knowledge and skill in his duties, and supported by integrity and by kindness. Our captain understands his men, and knows how to infuse some of the energy of his own character into the execution of their appointed tasks; and their cheerful obedience, based on their respect for him, is its own reward, adding a pleasant zest even to their labours. To say, in addition to this, that he is well versed in Euclid, algebra, trigonometry, in the application of these to mathematical navigation; that he knows the laws which govern the magnetic needle; that he is expert in the use of the instruments by which the *data* are obtained for ascertaining the position of his ship; that he has a knowledge of the stars, and their use in the narrow bounds of his practical art; that he is acquainted with many leading marks for guiding his vessel safely into port; that he knows the great currents of the air, the trade-winds, the monsoons, and the character of their periodicity; that he knows the great currents of the ocean, and how to estimate and allow for their effects; that he is acquainted with the fluctuations of the tides, and perfect in the management of the machinery of the ship; what sails he should carry, and guided by the face of the sky, when he should furl them; to say all this is only to say that he is something of a sailor, and, with his men, forms the animating principle of the huge mass of timber, iron, copper, and hemp, which make his ship.

12. The moral qualities above mentioned, and that section from the stores of human knowledge and experience which are indispensable to his station, merely make him a fit instrument for the performance of the most obvious duties for which he is hired—a good servant to the owners of his ship, who are his masters, and a good master to his men; and thus within these con-

tracted limits he does his duty to his neighbour. But he is a man in a world of men, and, having accomplished thus much, may do much more, for "they who go down to the sea in ships and do business in the great waters, these see the works of the Lord and his wonders in the deep."

And if, while impressing these glorious truths on those around him, he enlarges the boundaries of his own scientific and exact knowledge, he has extraordinary opportunities for verifying it by direct comparison with nature in her various aspects as they are seen in different lands,—and with even a slight knowledge of botany, natural history, chemistry, or geology, he will add to his rational pleasures and find familiar friends in every department of the lovely face of nature—and may aid in extending our acquaintance with them by revealing new truths; and then from an obedient and faithful servant he rises into a public benefactor.

13. We must remember that the true end of learning is not the mere satisfaction of a vain curiosity; the study of the wondrous works of God, when rightly directed, elevates the intellect, and makes it a more fitting abode for the higher truths which relate to the spirit of man that never dies. It should render every one in his station a missionary of the Lord of heaven and earth, who condescended to take upon himself our nature and to go about doing good, and fit every one, under His blessing, for companionship with the "spirits, of the just men made perfect."

LESSON II.

THE OCEAN—THE WINDS.

1. Few persons living in the neighbourhood of a large city can be unacquainted with the idea, and the phrase which pictures it, of "losing oneself" in the intricacies of its courts and lanes, nor with the sense of relief with which the familiar sound of a bustling thoroughfare first breaks upon the ear, followed shortly after by the grateful sight of a well-known shop, or such a headland as Temple Bar, by which we once more "find out where we are." This common accident happens hundreds of times, and dies in the mind, without once awakening the attention to the curious and interesting features which it presents.

2. What is meant by "knowing where you are?" The man who thus, as the phrase goes, feels "quite at home" in the neighbourhood of objects or scenes with which he is acquainted, would often be puzzled to point in a direct line to his own residence, and would probably "lose" himself half-a-dozen times on his way to it, if

compelled to rely solely on his own information. His satisfaction rests on the assurance that he can now proceed eastward, westward, northward, or southward to the station from whence the conveyance starts, which will carry him home; and thus his own limited knowledge leads him to avail himself of the knowledge of others, and results in the attainment of his desired haven. He "knows where he is," when he recognises a place which suggests to him the means of arriving at another place where he wishes to be.

The faculty which he is called upon to exercise is that of *observation*, and more or less *attentively*, in inverse ratio to the number of familiar objects presented to his view, and assisting him in the verification of his "whereabouts." On his return he will probably spread out his map, and make use of his little misadventure to extend his acquaintance with the geography of the town; and thus transmute his experience into available practical knowledge.

3. The difficulty, I have said, generally increases with the paucity of points of reference; it also increases with their distance.

The poor emigrant approaching London on foot, with the intention of reaching the docks, finding himself "all at sea" in its increasing perplexities, humbly asks a passer-by, where and how far off lies the great church of St. Paul? and thitherward bends his steps with renewed hope and vigour; and from thence taking a new departure, with the aid of friendly hints, arrives at his destination. Two months hence he is on the sea, below him the waves perpetually changing; though even there he sees, in the repetition of their forms, the evidence of a great governing law. He sees no link between his present and his old loved home; he casts his eyes heavenward as he did when struck on that weary evening with the grand dome of St. Paul's, and there he sees the same stars in the same unchangeable order, there he finds the lost link between his old world and the new.

4. In these few remarks, the connection of astronomy and geography with the art of navigation may be already traced, and the use of maps, both of the heavens and the earth. As landmarks become fewer and by degrees vanish away, the observations of them must become of a more severe and discriminating character, and this is still more the case with the use of the stars in determining situations on the surface of the globe. Mechanical aids of a refined and scientific character are then employed for their more perfect accomplishment. Still the question remains, how is he to find his way who sees nought but sky above and sea below him? how is the identification of a place to be assured, so that a needle-point may be laid upon the globe or map, and the pilot say authoritatively, thus far have we come?

5. How wonderful is the versatility of Nature! how great the variety produced by elements fundamentally the same! Look at the crowd in London, where are there two faces which resemble each other—nay, where are there two features alike? Look at the plants, the leaves, the stems, the flowers. Everywhere is there evidence that no two points of earth or sea lack some characteristic by which they may be distinguished from each other, if observation intent enough be brought to bear upon them.

6. Physical geography and hydrography, as exhibiting in a striking manner the bolder outlines of the surface features of our globe, will furnish the elementary steps in the solution of the questions above proposed.

First, in the dreary regions around the north pole, the sun barely glances over the surface of the sea; the stars of the northern hemisphere circle round and round about a point nearly overhead, varying comparatively little in their elevation during their daily revolution, and yet show by this that the pole, with its supposed open ocean, to which so many expeditions have been directed, is not yet reached. It will hardly be necessary to direct attention to the ice-bound sea, the dreary

and barren shore, with its scant and stunted vegetation; the seal, the walrus, the whale, the bear, the white-coated fox, the shrieking sea-birds, the lichens and the mosses, the inhabitants of earth and sea and air, the aspects of the sun, the moon, the stars, the aurora borealis with its purple streamers flashing in perpetual change, distinguish this region from all others.

Next, advancing step by step towards the south, the sun and stars on that side of the heavens are seen to lift themselves, as it were, higher and higher above the horizon, owing to the convexity of the globe; and thus teach us to associate their altitudes with our distance from the equator, and furnish the navigator with a means of exact mechanical measurement of that important element of position to which astronomers and geographers have given the name of latitude.

The pole-star, which stood overhead in the frozen zone, has sunk gradually towards the horizon in steady accordance with our southern progress, its altitude growing less and less with our diminishing latitude.

7. But, not the sun and stars alone are telling of our onward course; we are now passing through that great ocean river, called the Gulf-stream, which comes rushing from the great cauldron of Mexico, bringing on its ample bosom the genial influences of the sunny south, even to the shores of our native land, adding another to the many unseen blessings which scientific research makes known, startling the grateful heart into praises to the bounteous Giver of all good. Here the thermometer becomes not only an instrument of speculative and philosophical research, but a direct aid to the navigator, who is always on the alert to interrogate the elements, which become to him full of eloquence, "though without speech or language." At the bottom of the Gulf-stream the temperature of the water has been noticed to be 38° Fahrenheit, when on its surface it is 80°. The absence of the right-whale from this great artery of the sea, and the frequency of the delicate and lovely corallines and zoophytes of tropical regions, and the

starry spangles of their beautiful phosphorescent scintillations, are all to him significant indications of his progress.

Next, we enter the great basin of the Atlantic, where the gulf-weed, accumulating in the dead water, gives to the ocean the appearance of verdant fields. This, the remarkable Sargasso sea, was seen by Columbus, and alarmed his companions in his voyage of discovery; it constantly retains the same limits, and furnishes a mark on the surface of the ocean which can hardly be mistaken.

8. Still pursuing our onward course, the temperature continually increasing, until it becomes scorching with a vertical sun; the tropics are reached with their calms, and their storms, tornados, whirlwinds, and waterspouts; the vivid lightning and the loud-voiced thunder here speak to the awe-stricken mariner in a voice to which ignorance and superstition may add new terrors; yet may they well arouse the sleeping souls of good and bad, of wise and foolish, to reflect on the dreadful powers by which we are surrounded, the great agents by which the balance of the elements is restored and Nature refreshed and renovated, and on the goodly and godly gift of reason to man, who, by the aid of science, not only learns to protect his ships from destruction, but can reduce even the electric fluid into an obedient messenger swifter than light, almost annihilating in its rapidity the ideas of time and space.

Let the seaman look into the heavens above, into the atmosphere whose terrific powers have been hinted at, and again into the sea beneath him; here are the dolphin, the bonito, the flying-fish, the voracious shark, the sperm whale; the corals, with their myriads of busy architects; and on the sunny isles of this belt flourish the palms, the banana, the sugar-cane, and all the wild luxuriance of tropical vegetation.

"O Lord, how manifold are thy works! in wisdom hast thou made them all: the earth is full of thy riches.

"So is this great and wide sea, wherein are things creeping innumerable, both small and great beasts.

"There go the ships; there is that leviathan, whom thou hast made to play therein.

"These wait all upon thee, that thou mayest give them their meat in due season."—Psalm civ. 24—27.

9. Here, too, do we enter the regions of the trade winds, those remarkable atmospheric phenomena which play so important a part in navigation. The air, more immediately exposed to the action of the sun's rays, becoming heated and rarefied, ascends to the upper regions of the aerial ocean, whilst its place is continually supplied by cooler and heavier air from the higher latitudes north and south of the tropics; but the air so substituted brings with it a slower rate of rotation from west to east, than is possessed by those parts of earth and sea which it has now to cover; the earth then, and those who dwell upon it, are dragged through the lazy air, and the impression which it leaves is that of a wind from the eastward, and at the same time from the northward in the northern and from the southward in the southern hemisphere, causing the north-east and south-east trade winds.

The counter pressures from the north and south, and the gradual assimilation which takes place between the motion of the earth and that of the incumbent air, produces that belt of calms called by the sailors by the significant name of "the Doldrums."

10. The atmospheric phenomena encountered in the tropical regions are graphically described by Lieut. Maury:—

"Seafaring people have, as if by common consent, divided the ocean off into regions, and characterised them according to the winds, viz., the 'trade-wind regions,' the 'variables,' the 'horse latitudes,' the 'doldrums,' &c.

"The 'horse latitudes' are the belts of calms and light airs which border the polar edge of the north-east trades. They were so called from the circumstance that vessels formerly bound from New England to the West Indies, with a deck-load of horses, were often so

delayed in this calm belt of Cancer, that, for the want of water for their animals, they were compelled to throw a portion of them overboard.

"A vessel bound into the southern hemisphere from Europe or America, after clearing the region of variable winds and crossing the 'horse latitudes,' enters the north-east trades. Here the mariner finds the sky sometimes mottled with clouds, but for the most part clear. Here, too, he finds his barometer rising and falling under the ebb and flow of a regular atmospherical tide, which gives a high and low barometer every day with such regularity, that the time of day, within a few minutes, may be told by it. The rise and fall of this tide, measured by the barometer, amounts to about one-tenth of an inch, and it occurs daily and everywhere between the tropics; the maximum about 10h. 30m. A.M., the minimum between 4h. and 5h. P.M.; with a second maximum and minimum about 10 P.M. and 5 A.M. The diurnal variation of the needle changes also with the turning of those invisible tides. Continuing his course toward the equinoctial line, he observes his thermometer to rise higher and higher as he approaches it; at last, entering the region of equatorial calms and rains, he feels the weather to become singularly close and oppressive; he discovers here that the elasticity of feeling which he breathed from the trade-wind air has forsaken him; he has entered the 'doldrums,' and is under the 'cloud-ring.'

"Escaping from this gloomy region, and entering the south-east trades beyond, his spirits revive, and he turns to his log-book to see what changes are recorded there. He is surprised to find that, notwithstanding the oppressive weather of the rainy latitudes, both his thermometer and barometer stood, while in them, lower than in the clear weather on either side of them; that just before entering and just before leaving the rainy parallels, the mercury of the thermometer and barometer invariably stands higher than it does when within them, even though they include the equator. In crossing the

equatorial doldrums, he has passed a ring of clouds that encircles the earth."

11. Everywhere we are witnesses of the efficacy of heat in producing great changes in the aspect of nature; how enormous must be the aggregate mechanical power called into action in the bursting of the leaf-buds in one forest in spring, in the lifting of the sap into the leaflets at the summits of the trees, and in the mysterious growth and extension of the leaves and branches!

The simplest experiments of a lecture table produce evidences of electricity, arising from the most trifling friction, by the operation of heat, and by chemical action; how great, then, must the development of this gigantic agent be in the rapid growth and decay of vegetation of the torrid zone, where all the exciting causes are in constant and excessive action!

It is not wonderful, but follows as a necessary consequence for the restoration of the balance of nature, that this region should be the nursery of those fearful storms, of which modern science is happily interpreting the laws, and reducing them to so intelligible a digest, as to render it nothing short of culpable negligence in any one having to do with the navigation of a ship, who shall be found ignorant of the plain rules laid down for his guidance in the works of Redfield, Reid, Piddington, and Thom, on the storms of the Atlantic and Indian Oceans, and which have been since extended to the South Pacific by the labours of Dobson.

12. Not only is the nature of revolving storms well understood (the winds turning round the centre in the direction of the hands of a watch in the southern hemisphere, and in the contrary direction in the northern hemisphere), but indications of their approach by the falling of the barometer and the veering of the wind, are unmistakable, and warn the intelligent mariner in what direction the fearful centre of the "cyclone" lies, and which way it is travelling; and thus he is enabled to prepare for it. By his knowledge of them he may sometimes avail himself of a fair wind on its outskirts,

or he may run away from dangerous proximity to the centre of the whirl; or at the worst, if compelled to "lie-to," he will know how to do this on the right tack, so as to be certain that the gale shall not veer round by the head of his ship and so take her aback.

13. The cyclones in the North Atlantic have their origin to the eastward of the West Indian Islands, in latitudes from 10° to 40° N.; they are vast whirl-winds, in which the wind blows round in a direction opposite to that of the motion of the hands of a watch. The centre moves onward in a north-westerly direction towards Florida, when its course becomes more nearly north, and then it bends towards the north-east, and follows very nearly the course of the Gulf-stream, while the circle of air involved in it is gradually extending.

In the Indian and Pacific Oceans they also have their rise within the tropics, in the Indian Ocean sweeping away from the equator and towards the west; but in the South Pacific, analogy, the most tempting substitute for reason, is disappointed, for there Mr. Dobson has shown that their track is towards the south and eastward.

This subject is of such great importance to navigation, and has yet taken so feeble a hold on the attention of seafaring men, that it has already claimed a larger space than accords with the aim and intention of this lesson, which is not that of scientific disquisition, but to direct attention to a few of the scientific aids of navigation.

LESSON III.

THE COMPASS—THE LOG—AND THE CHART.

1. In the two preceding lessons, an attempt has been made to show to the young student what aids the observant seaman may receive through a general knowledge of the natural sciences, and the advantages of going through the world with the eyes open and the attention constantly awake. We must now approach

those more exact methods which constitute, in ordinary acceptation, the sailor's professional education.

It has already been stated that the skill of the navigator consists in the utmost refinements of the ordinary habits of observation, and that the senses are to be assisted by instruments often of an extremely delicate construction. The indications which these instruments furnish are afterwards to be subjected to the crucible of mathematical reasoning, to the stern and undeviating truthfulness of geometry.

2. Geometry, indeed, lies at the root of almost every useful practical art: it recommends itself to the engineer, the astronomer, the mechanician, the navigator, to all of whom it is indispensable—and then to all who desire—and who does not!—to train and discipline their spiritual nature, to fit it to approach with understanding—and rightly and justly to reason upon the marvellous works amongst which we dwell, stamped visibly, to those who will learn to see, with the seal of His knowledge who hath made all things. Dr. Whewell says—"The recollection of the truths of elementary geometry has, in all ages, given a meaning and a reality to the best attempts to explain man's power of arriving at truth."

Upon the firm rock of geometrical truth have been whetted the brightest intellects whose works illumine and adorn the pages of a nation's history.

Distance, direction, and relative position, are the talismanic words of navigation, and these are essentially the property of geometry, whose subtle analysis is to be appealed to whenever they are subjects of inquiry. The standard of direction is the meridian passing through the place of the observer. The earth being supposed a sphere, the meridian is the circumference of that plane section of it which passes through these three points, viz.: a pole, the centre of the sphere, and the place of the observer. It is a circle whose centre coincides with the earth's centre; it is moreover called a great circle, for none greater can be drawn on the surface of a

sphere. Although it has been stated as a condition of the position of the circle that it passes through one pole, it must of *necessity* pass through the other pole also. Now, a portion of this meridian line being drawn on the surface of the terrestrial sphere, the opposite ends of it towards the northern and southern hemisphere are denominated the north and south points (fig. 4).

MARINER'S COMPASS.

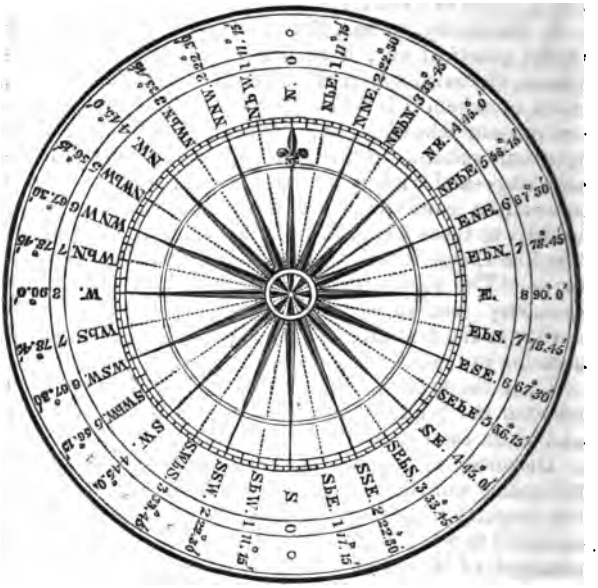


Fig. 4.

A line at right angles to the meridian points to the east and the west; when you face the north, the east is on your right hand and the west on your left. These two lines divide all the horizontal space by which you are encompassed, into quarters, called the four quarters of

the compass, and distinguished as the north-east, north-west, south-east and south-west quarters. The right-angles formed by the intersection of these lines being bisected (Euc. I. 9), the directions of the four new lines pointing *from* the middle of the primary cross receive a double name from those of the *cardinal* or chief points, also designated as the N. S. E. W. These new directions, then, are called N.E. (north-east), S.E. (south-east), N.W. (north-west), and S.W. (south-west). The initial letters N. S. E. W., you perceive are used as contractions for the names of the cardinal points. If the half-right angles obtained by the former bisection be again bisected, eight more lines are obtained proceeding from the centre or station of the observer, and the directions of these also derive their designations from those between which they lie, as N.N.E. (north north-east), between north and north-east. The others on the same principle are called, N.N.W., S.S.E., S.S.W. So again, the middle direction between E. and N.E. is called E.N.E. (east north-east); between W. and N.W., W.N.W.; between W. and S.W., W.S.W., and between E. and S.E., E.S.E.

Distinguishing names have thus been bestowed on sixteen different directions or *rhombs*, or *points of the compass*. By another bisection of the angular spaces between these *rhombs*, sixteen other *points* are obtained which however receive their denominations on a different principle from those already mentioned. Thus, the point between N. and N.N.E. is called N. b. E., that between N.N.E. and N.E., N.E. b. N., that between N.E. and E.N.E., N.E. b. E., and the one between E.N,E. and E., E. b. N.: it will be seen that this new series receive their designations from the four cardinal points, N., S., E., and W., and from those which were first derived from them, N.E., N.W., S.E. and S.W.; these with the affix b. N., b. S., b. E., or b. W., according as the point to be named lies on this or that side, furnish names to these additional points, making in all 32 points of the compass, depending as

we see on the meridian, whose direction it is evident we must know.

3. What could have suggested to men's minds the notion of this fundamental line? How can its position be determined, especially in a ship tossed about upon the waves of the sea? heaving, pitching, rolling, yawing, all the vocabulary of motion must be exhausted in describing the apparently ungovernable mobility of a ship!

The first of these questions belongs to the astronomer. Every elementary treatise on astronomy explains how the rotation of the earth brings the edge of that circle which bounds our view, and which is called the horizon, successively to the various objects which gem the sky, and then, passing onward, makes them seem to rise higher and higher above the surface of the earth, until in mid-heaven they culminate or attain their greatest elevation; and then the western side of the horizon, sweeping upward in its perpetual round, like the sickle of time, devours them again from our sight, and one by one they seem to sink into the mysterious gulf of the west. The glorious awakening of day, and its solemn close with its purple sunset, mark, by their constant alternations, the onward current of our lives, and suggest a far greater change than from day to night and night to day, and are the most striking of these consequences of the earth's rotation—the shortening shadows of the morning, and the lengthening shadows of evening, are amongst the phenomena which perhaps earliest rivet the attention and develop the germ of thought in our childhood. At noon, when the sun attains his greatest altitude, the shadows are shortest and lie directly north and south, thus marking visibly on the surface of the earth the position of the meridian line. This method, confessedly of the rudest kind, will at least show the possibility of securing a permanent tracing of the direction of the meridian on shore. An improvement on this method consists in procuring a smooth, flat, horizontal slab of stone, upon which must be drawn a

circle, and then it must have an upright style or needle in its centre: the instants must then be watched at which the extremity of the shadow of the style just touches the circumference of this circle in the morning and in the afternoon, markings being made at the two points where these contacts occur; if the distance between these points be accurately divided into two equal parts, and a *line* be drawn through the point of bisection from the foot of the needle, this line will be the meridian very nearly.

4. Looking southwards along the line thus drawn, it is probable that it may be seen to tend towards some striking object in the distant horizon, and attentive watching will show that the sun, the moon, and all the stars in succession attain their greatest altitudes when vertically over this object, which represents the *south point* of your horizon, and it is this which has invested the meridian line with its especial interest. The methods above described—if they may claim to be dignified by such an appellation—are evidently valueless at sea. Here we have been assisted by *light;* there we invoke the aid of *magnetism.* This last subject has been fully discussed in another portion of the lessons of this book, and we are therefore not called upon here to enter upon any details concerning the manufacture of the magnetic needle, nor indeed to do more than to hint at its leading properties.

5. Well, then, in this little bar of hardened steel is locked up that wonderful guiding power which has exercised the widest influence on Navigation: an instrument, let us hope, for the fulfilment of the sublime prophecy, that "the earth shall be full of the knowledge of the Lord as the waters cover the sea." (Isaiah xi. 9).

A circular card having been procured and divided by radiating lines as described in the preceding part of this lesson, the magnetic needle is to be firmly attached to one of the intersecting diameters the whole; is then to be accurately balanced on a pivot in the centre.

The needle then settling *towards* the meridian, gives

the mariner a means, after certain corrections are applied, of ascertaining the direction of the meridian and the various points of the horizon, and he is thus enabled to *shape a course* on which he desires to proceed; and he also notes the direction of the wind, that he may make a faithful record in his *log-book* of all the circumstances in which the valuable property of his employers has been placed during the period of his stewardship.

When he is sailing along a well-known coast—that is, one which has been efficiently surveyed, and of which minute pictures, or plans, or *charts*, as they are called, have been diligently and faithfully constructed—the compass affords the most speedy and therefore the most valuable means which the sailor possesses of ascertaining the position of his ship with respect to the land, and to the hidden sand-banks and rocks which lurk beneath the water, threatening destruction to the hopes of his voyage and the lives of those who depend upon his vigilance.

6. The accompanying diagram (fig. 5) will illustrate

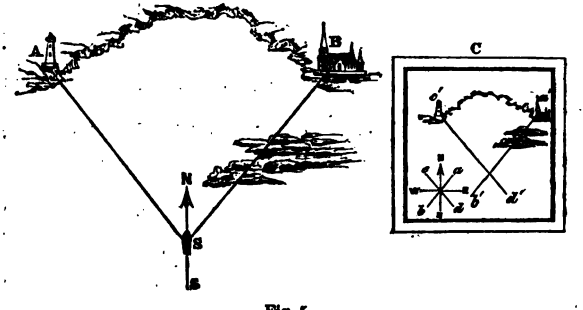


Fig. 5.

this: suppose A and B to be a church and a light-house visible from a ship, at S, in the offing; a reef of rocks is represented between the place of the ship and

the church. The captain, consulting his compass, observes that the church lies north-east, and the light-house north-west of him. He then takes his chart (C), upon which you see the objects are also marked in their proper positions, and in one corner is a compass divided as his ship's compass is (many of the lines are omitted in the diagram to prevent confusion). He lays a pair of parallel rulers over *a b*, which is the N.E. and S.W. line, and moving them carefully into the position *a'b'*, he draws a light pencil-line through the church, then placing them on *c d*, the N.W. line, he again moves them into the position *c'd'* and draws this line; the intersection of the lines *a'b'* and *c'd'* shows him where he is with respect to the reef of rocks, and therefore how to avoid it. If this process be frequently repeated, a series of points representing upon the map the successive positions of the ship will be found, and a line drawn through them will show the track, or very nearly the track, which the ship has followed.

7. Lines are also drawn upon many sea-charts, marked with their proper *magnetic bearings*, by means of which ships may be placed in a good position for anchoring, or may avail themselves of the best channels for *making* or leaving their port.

The distinction between *magnetic* and *true* bearings must be clearly and early established in the mind of the young student of navigation. The magnetised needle does *not* point in the direction of the true meridian, nor does it, in all parts of the world, deviate from this direction by the same amount. If a compass be placed over the meridian, as determined by one of the astronomical methods above related, it will be seen that the N. and S. line of the compass crosses the meridian, and that at Greenwich they make an angle of about two points between them, the north point of the compass card being turned about two points to the westward of the *true* north; and the N.N.E. point of the compass nearly coincides with the *true* north. This will throw every point of the compass two points to the left of its

proper place, and it is this difference which is called the *declination* or *variation* of the compass. The importance of the distinction between the magnetic and the true bearings will therefore be easily understood.

In a ship the iron used in its construction also affects the direction of the compass-needle, and in different degrees, and in different directions according to the eastward or westward position of the ship's head: for the methods of *swinging* ships, and separating this variable source of error from the variation, and of estimating its amount, the reader must be referred to the special article on magnetism contained in this series.

8. It is of more importance to the sailor to be able to discover the total effect of all the disturbing causes which influence the directive power of his compass. And the method he employs may be thus briefly described:—the magnetic direction of the sun, or some well-known star, is observed with the compass, and then its actual bearing is computed from the astronomical elements of the star's position at the time, and these are found in the 'Nautical Almanac.' A knowledge of *spherical trigonometry* is necessary in this, and almost every other astronomical problem. Next, the computed true bearing and the observed magnetic bearing are compared with each other, and their difference, if any exists, is the combined effect of the variation of the compass and the local deviation.

9. The direction in which the ship is moving is judged by the steersman, who observes what point of the compass coincides with a mark on the compass-box, placed there to indicate to him the direction of the fore-and-aft line of the ship. Not that he believes the ship to be moving in the direction of her length, for she is under the influence both of the wind upon her sails, and of the resistance of the water through which she is moving; and between these two forces she makes a compromise, as it were, progressing nearly in the direction in which her head lies, but more or less to

the *leeward*, according to the strength of the wind, and the angle it makes with the side of the ship.

10. The amount of this deviation of the ship's track from the direction of the fore-and-aft line is called *leeway*, and experience, that wary and ancient teacher, is the seaman's guide in estimating its amount in the various circumstances in which he is placed. This then is sometimes another allowance he has to make upon the indications of his compass; nor is this all, for the whole body of the water may be moving and drifting the ship with it, without altering in the least her apparent course. If the current is running in the same direction as that in which the ship is urged by those forces already mentioned, no alteration of the ship's course will ensue, nor indeed, if the current should run in a direction diametrically opposed to this: the only effect then is, that of increasing or diminishing the rate of the ship's motion by the whole amount of the rate or *drift* of the current, as it is called.

If, however, the setting of the current cross the track which the ship would have pursued without its interference, then both the course of the ship and its rate will be affected by this new disturbing force, in a degree proportioned to its strength.

11. In the annexed diagram (fig. 6) let A B be the direction and distance which the ship would have gone supposing no current had existed, and let B C be the direction and the drift of the current in the same period of time, then A C will represent the actual track of the ship under these circumstances, and it will be at once seen that her rate has been increased, and her course made more westerly by the westerly run of this current.

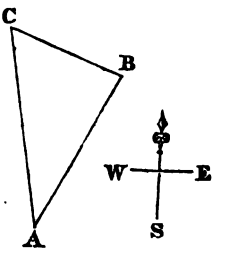


Fig. 6.

This will serve to show how an allowance can be

made for the effect of a current whose direction and rate are known, when the rate also at which the ship is moving through the water has been ascertained.

12. What better method could be devised for reckoning the distance you run upon the ground, than that of thing a measuring tape to a log, and then, while running, letting the line slip lightly through the hand, so that the log may not be displaced, nor your line broken? Now this is just the method in ordinary use at sea. A piece of wood of the shape depicted in the margin is attached to a long line, divided by certain marks into lengths called knots, each equal to $\frac{1}{120}$ of a nautical mile. The log is thrown overboard, and being weighted at its curved edge, stands perpendicularly in the water with its face towards the ship, and protected from the action of the wind which is urging the ship onwards: the line is then allowed to slip lightly out for 30 seconds or $\frac{1}{120}$ part of an hour, and the knots which have passed being reckoned, tell how many miles per hour the ship is advancing through the water. The length of the knots should be examined from time to time, as well as the sand-glass with which the time is measured, and if either or both should be found to be inaccurate, a correction must be calculated and applied to the estimated rate.

13. The *compass* and the *log* are the instruments by which the common journal of a ship's voyage is carried on; from hour to hour her compass, course, the wind, and the rate of the ship, with any other particulars worthy of note are entered on the *log-board*, and every day at noon a reckoning is made of her progress, and of her place upon the world.

The *compass* and the *log*. How many weak places have been indicated in the thread which they weave between the sailor and his home! The continuous zig-zag path which by their aid the sailor marks upon

his *sea-chart*, if not checked by other means, would perpetuate any error in the reckoning which might be accidentally, inadvertently, or carelessly made; every error of observation, of calculation, of instrumental imperfection, or of ignorant interpretation, by any one to whom the watch might be intrusted. The captain's skill would be set at nought: indeed it would be but a name—a sound signifying nothing. How can he assure himself that all has been well in the few hours which nature has demanded of him for the restoration of his physical power and mental health by sleep? The steering of the ship is intrusted in rotation to his men: are they all careful? are they all faithful? Unsuspected currents, too, may have swept the ship from her intended track, and, as we have seen, may have falsified the statements of our two silently-eloquent watchmen, the *compass* and the *log*.

LESSON IV.

THE SEXTANT, THE CHRONOMETER, AND THE NAUTICAL ALMANAC.

1. It is now that the captain must avail himself of such astronomical skill as he may possess: it is now that he has an opportunity of asserting the superiority of his scientific training over that of the ignorant and boastfully confident man who "trusts" that all will be well with him, and invokes, nay claims as a right, the protection of that bountiful Providence whose instructions he indolently and arrogantly refuses to receive.

But, for our captain, the sun, the moon, the stars in their eternal round are enlisted with him in his labour; he compares the feeble, wavering efforts of poor humanity with the great truths written in the heavens, and the light of a thousand suns makes clear his way across the pathless sea.

2. In order to avoid unnecessary repetition, it must

be assumed that the reader has carefully studied the articles on astronomy contained in this series: and that he has familiarized himself with the technical terms in common use in this branch of science; that he knows that the *declination* of a heavenly body means its angular distance north and south of the celestial equator. And that this element of the position of the heavenly bodies, in the case of the sun is subject to an annual fluctuation between 23½° north and 23½° south, as a consequence of the inclination of the axis of the earth to the plane of the orbit in which it moves. He will have learnt little indeed if he does not know that this is one of the many beneficent ordinations for which his daily thanksgivings are due: that it is this which produces seed-time and harvest, and on the regular periodicity of these changes depends our "daily bread."

3. The 'Nautical Almanac' is a book issued annually by the British government, for the special use of astronomers and navigators; and contains predictions as to the places of a large number of the sailors' celestial monitors for several years in advance; so that the sailor who is starting on a long voyage may not be embarrassed for the want of such important information if the period of his absence should run over two or three years.

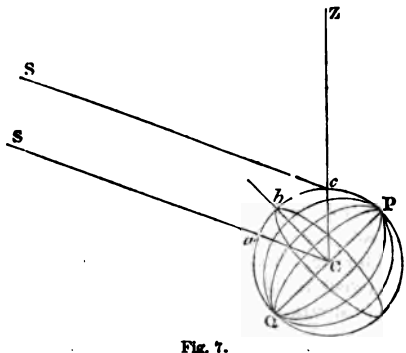


Fig. 7.

4. In the annexed diagram (fig. 7) the globe is intended to represent the earth, P and Q the north and south poles. C the middle point or centre of the earth, *c* the situation of the observer, C S and *c* S lines pointing to the star S which is vertically over *a*, *a* being,

as you will perceive, on the same meridian, P *c a* Q, on which the observer himself happens to be. Once in every apparent diurnal revolution each star thus presents itself on the meridian.

The lines C S and *c* S are nearly parallel: the moon, our nearest neighbour, is 240,000 miles distant, the sun 95,000,000, and the fixed stars immeasurably farther, and to these enormous distances must these lines be produced before they meet each other. The angle *b* C S is the declination of the object S, and is to be sought for in the 'Nautical Almanac.' Now, if we have the means of measuring the angle Z C S, or (which is very nearly the same thing, on account of the near parallelism of the lines C S and *c* S) the angle Z *c* S, we shall immediately know the latitude of the point *c*: for the difference, in this case, between the angle *b* C S and Z C S is the angle *c* C *b*, which is measured by *c b*, and this is the latitude of *c*.

Our captain then, if he can but measure this angle Z *c* S, will know his latitude, and independently of any previous record of his change of place; and can thus compare the language of the stars with the assertions of the compass and the log on which his reckoning has been hitherto depending.

5. Suppose a flat piece of wood of the shape of a quadrant, like that in the adjoining diagram (fig. 8), to be divided along its curved edge into 90 equal parts or degrees, commencing the division from the point next the eye: and these degrees to be numbered. Let a plummet also hang from the centre *c*: *p c* produced upwards points to the zenith Z. Now let the edge *m c* be directed to the star S, and the angle Z *c* S, or its equal *m c n*, is measured by the degrees in the arc *m n*, which

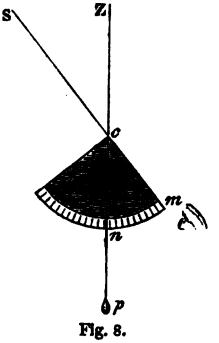


Fig. 8.

may now be at once read off. The rude instrument here described can claim at best to be considered as a scientific toy, very well in the hands of a schoolboy commencing the study of trigonometry, who by means of it may determine roughly the height of a church or a tree. It serves, however, a higher purpose in this illustration of its use, by showing the possibility of bringing mechanical aids to astronomical admeasurements.

6. The sextant, of which a drawing is annexed (fig. 9), is the instrument used by navigators for the

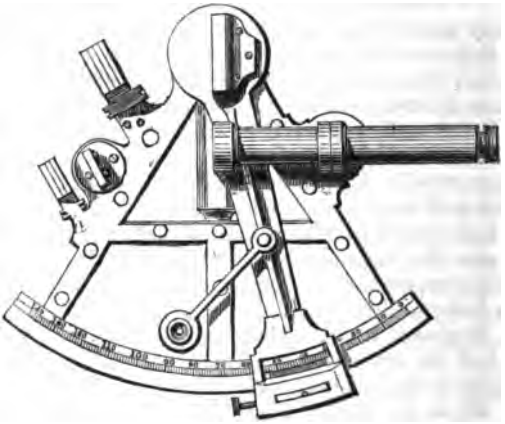


Fig. 9.

purpose of measuring angles, and is not restricted to the vertical position, as is the humble instrument just described. The optical and mechanical principles of its construction would lead us into details unfitted for the simplicity of a reading-lesson; and must therefore be sought in their legitimate places: viz., in the formal Treatises on Navigation and on Optics. But it may be mentioned, that as no instrument made by human hand is perfect, much of the difficulty in using the sextant aright consists in the careful examination of it for the

purpose of detecting its errors, to some of which mechanical correction is applied by means of screws, &c.; the effects of others are estimated, and allowed for, after the completion of the observations.

7. We are now to suppose that the *latitude* has been determined by means of the meridian altitude of the sun or some other bright star. Our captain now knows how far he is north or south of the equator; but this is not enough, he must next ascertain his *longitude*, or how far he is to the eastward or westward of the meridian of Greenwich. This may be further illustrated by the annexed diagram.

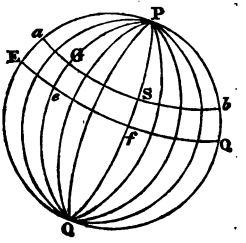


Fig. 10.

This figure (10) represents the globe: the circles which meet in the poles P and Q are meridians. G we will suppose to represent the situation of Greenwich, and P G Q the first meridian. E Q, a great circle equidistant from P Q, is the equator, dividing the northern from the southern hemisphere. Now, if the latitude *s f* of the ship be found, then it will be known that she is somewhere on the parallel *a b*, but not at what particular point of this parallel; but if, in addition to this, the longitude *e f* can also be discovered, it will also become known that she is upon the meridian P S Q, and therefore at S, where the meridian and parallel cross each other.

It is principally for the purpose of finding his longitude that the mariner carries a *chronometer* to sea.

8. The chronometer is a watch or time-keeper of very refined construction, with contrivances to insure the regularity of its going in all climates; and if it may be said, that its performance leaves something still to desire, it must be admitted, on the other hand, that a good chronometer is an instrument of astonishing delicacy, and that scientific and practical skill have been

very highly taxed in its manufacture, and the result is a triumph of human ingenuity.

By means of this instrument, the navigator knows the time at Greenwich wherever he may happen to be; but he must first know how much it was too fast or too slow on a certain day, and also be careful to make himself acquainted with its *rate*, as it is called—that is, how much it *gains* or *loses* per day; for it is almost certain to do the one or the other; and all that is to be expected of the best is, that this daily gain or loss is not a fluctuating one.

9. Suppose that on January 8th a chronometer was too fast by two hours twenty minutes, and that this *error* was increasing at the *rate* of five seconds per day. How much would it be too fast on the 28th of January? In twenty days it would have gained one hundred seconds, or one minute and forty seconds, and this added to its former error, would make it two hours twenty-one minutes forty seconds fast. A correct knowledge of the Greenwich date enables us to avail ourselves of the contents of the 'Nautical Almanac.' The right ascensions, declinations, &c., of the sun, moon, and planets are therein tabulated for the noon of every day at Greenwich, and hence a knowledge of the Greenwich date is indispensable for the calculation of them for intermediate epochs.

We shall presently see also how the true Greenwich date enables the seaman to discover his *longitude*.

Does not every one connect the idea of time with the motion of the sun? Day and night, the most visible stamp of Time's footsteps on the sands of life, are marked by the alternate presence and absence of the light of this great star. Dawn, early morning, sunrise, are synonymous terms. So are evening and sunset.

The vague association of the sun's place in the sky with the time of day thus marked in the language of all countries becomes an important and significant fact to the astronomer. He observes that, as time advances, the altitude of the sun increases in the morn-

ing until noon, and then decreases as he declines to the west.

10. The astronomer furnishes our captain with exact precepts for calculating the time at his ship, from the observed altitude of the sun, and of the stars also, whose regular movements he has discovered are available for the same purpose.

Our captain now knows both the Greenwich date and the date at the ship, what will he do with these strange possessions?

Need the reader be told that the Greenwich date and ship-date will differ if the ship be ever so little east or west of Greenwich?

As the earth turns upon its axis, every meridian is successively brought towards the sun, and as the complete rotation is performed in a day, meridians 15° asunder are thus brought to the sun at regular intervals of one hour; at each in succession it is noon, when to its predecessor it is one hour past, and to its successor one hour before noon.

For every fifteen degrees eastward or westward, then, there is a difference of one hour in the times at different meridians.

For example, suppose the captain to notice that it is noon at his ship when his chronometer informs him that it is two hours past noon at Greenwich: he will know that the sun is west of the meridian at Greenwich by twice fifteen or 30°, but he sees it now on his meridian; therefore his meridian is 30° west of Greenwich. In other words, his longitude is 30° W.

11. It is very desirable that our captain should have some independent means of checking his chronometer; for so delicate an instrument may be sadly deranged by a very trifling and unheeded accident.

Such a means offers itself in the monthly revolutions of the moon. The angular distance of the moon from the sun, and from certain stars, is calculated and tabulated in the 'Nautical Almanac' for every third hour of the day at Greenwich. Therefore, if the distance of

the moon from any of these objects be measured with a sextant, a comparison between the measured distance and those in the 'Nautical Almanac' will give the mariner the Greenwich time, without the intervention of the time-piece. An altitude of the sun or of a star will next give him the time at his ship, and the difference between the Greenwich date and ship-date is the longitude-in-time.

12. In the slight sketch here given of the methods employed for the discovery of a ship's place at sea, all minute details have been carefully avoided, such, for example, as the effect of the atmosphere on the direction of the rays of light, and the corrections to the observations on account of the earth's spherical figure. The object has been to present a broad view of the simple principles upon which the art of navigation is founded, and to show the identity between science and common sense. Whilst this view of things may inspire confidence in those who have a hearty desire to attain sound knowledge, beware that it does not beget over-confidence and its companion, negligence. Labour and learning go hand-in-hand: nothing is found that is not sought for. As the body becomes sluggish by inaction, so the mind becomes obtuse for lack of that healthy exercise which the study of science demands of it.

The paths are rugged and thorny by which we gain our first steps in knowledge. Persevere! and whilst we conquer, we acquire that manliness which we admire in men. Persevere! and the insuperable difficulty changes into a shadow before the bold front of determination. Persevere! you gain the power of doing good and being useful in your generation. All nature looks brighter to your cultivated understanding: treasures of delight are opened in the stores to which she invites your observation. Your heart warms to the majesty, the power, the wisdom, and the goodness of God!

JOHN RIDDLE.

MARINER'S COMPASS AND MAGNETISM OF SHIPS.

BY WILLIAM WALKER, R.N.

1. THERE are grounds for believing that the directive power of the magnet* was first discovered in China about 4490 years ago, and used as a machine to direct the march of an army. Dr. Balde, who was a Christian missionary in China, and wrote a history of that country, informs us that about the year 2634 B.C., a machine was invented; which, being placed in a car or carriage, pointed *to the south*, and enabled the imperial army to direct its march, and surprise the enemy during a thick fog. The same author relates, that about 2884 years ago, an embassy had reached the court of China, from Cochin, and that the ambassadors having experienced great difficulty in finding their way by land, on their departure, the Emperor "Ichun Kong" gave them an instrument, of which one end pointed to the south, and the other to the north, in order that the embassy might find its way home with less difficulty.

2. In a Chinese dictionary, compiled about 1500 years ago, the following passage is found. "They had then "ships, which directed their course to the south by the "*magnetized needle*." Again, "the fortune-tellers rub "the point of a needle with the stone of love to render "it proper to indicate the south." We see, then, that these early Chinese sea-compasses were probably not very dissimilar to those now in use in Chinese coasting-craft, viz., a sewing-needle rudely suspended in a wooden box. The Malays, Lascars, and other sailors of India had, no doubt, rude sea-compasses; for when Vasco de

* For the general principles of magnetism consult the article Magnetism and Electricity, vol. iii.

Gama sailed round the Cape of Good Hope, and through the Mozambique Channel as far as the coast of Malabar, he was much surprised to find many sea-going ships with mariners' compasses of an inferior kind in common use: this was, however, only three hundred and fifty-seven years ago.

3. The earliest mention made of the mariner's compass being used in European seas, is to be found in some old MSS., deposited in the Imperial Library of France, and written about the end of the twelfth century. Cardinal de Titri, a native of France, who, being engaged in the Crusades, became bishop of Jerusalem, wrote an Oriental history, in which he mentions that the Saracens, employed on the coast of Syria, used a compass to direct the course of their ships. There is an Arabian MS. in the Imperial Library of Paris, written in 1242, which gives a description of the mariner's compass at this early period. "We have to notice among the properties of the magnet, that the captains who navigate the Syrian seas, when the night is so dark as to conceal from view the stars which might direct their course, according to the position of the four cardinal points, take a basin full of water, which they shelter from the wind by placing it in the interior of the vessel; they then drive a needle into a wooden peg, or a cornstalk, so as to form the shape of a cross, and throw it into the basin of water prepared for the purpose, on the surface of which it floats. They afterwards take a loadstone of sufficient size to fill the palm of the hand, or even smaller, bring it to the surface of the water, give to their hands a rotatory motion towards the right, so that the needle turns on the surface of the water; they next suddenly and quickly withdraw their hands, when the two points of the needle face the *North* and *South*. They have given me ocular demonstration of this process during our sea-voyage from Syria to Alexandria in the year 642 (or A.D. 1242)."

4. There is, doubtless, much of jugglery and Arabic enchantment in the process described; but let the reader

allow a sewing-needle to touch a magnet, and then let him stick the needle into a "wooden peg or corn-stalk," and without making a cross of it, the needle will point in a north and south direction, when floating in a basin of water.

5. By the Crusades, which were carried on for two hundred years on the eastern shores of the Mediterranean, the seamen of Europe were brought into contact with those of the East. Italian mariners had, therefore, opportunities for observing the practical utility of the Saracenic compass, but the Christian might be induced to reject or even abhor the sight of the "wizard's stone," of the Arabian sailor. These wars terminated near the end of the thirteenth century, and commerce resumed its course throughout the Mediterranean seas.

6. In the present kingdom of Naples there is a small seaport called Amalfi, or Amalphi, which, in ancient times, was celebrated for its commerce, its ships, and the skill and enterprise of its mariners. A native of Amalfi, named Flavius Grogo, made so great an improvement on the Saracen's compass, that to him has been ascribed the honour of its invention: this happened about the year 1302.

7. The Saracen seamen, we have seen, resorted only to their compass when the nights were dark and no stars could be seen. The superstitious ceremonial of magnetizing the needle, and observing its pointing when afloat in a basin of water, were all performed between decks, or "in the interior of the vessel," and, therefore, such a compass could really be of no assistance to a man at the helm of a ship in the open air on deck.

8. The important improvement made by the mariner of Amalfi was, no doubt, what many of us have seen delineated in old books, namely, the suspension in gimbals of a wooden compass-bowl in a square box; the wooden bowl being a substitute for the Arab's basin: from the bottom of the compass-bowl rose a vertical point, for supporting the magnetic needle horizontally poised and free to turn round. Flavius Grogo, instead of using

water in his compass-bowl to float the needle, made his needle balance itself on the aforesaid pivot and traverse on an agate. The improved needle was large enough to support a circular card attached to its under side, and retained sufficient magnetism and directive power to preserve a constant bearing relative to the polar star in the heavens, or to surrounding objects on the earth. By covering such a compass with any transparent substance, as talc, or glass, it is evident the compass might be used on the upper deck, or open air, by the helmsman at all times.

9. The improvement thus made was immense, and soon led to important alterations in the form, magnitude, and employment of ships in every part of Europe. Before this time sea-going vessels seldom ventured out of sight of land: they were, in fact, coasting-vessels employed in summer only; fit for being hauled up on sandy beaches, or anchored in sheltered bays, or in the mouths of navigable rivers. Their trips from one anchorage to another were short; they required no great store of provisions, fresh water, or sails and rigging, for many of them were often propelled in calm weather by oars. But when a serviceable mariner's compass was contrived, which the helmsman could steer by, and the needle of which would permanently retain its magnetism, and point, under all circumstances, to the pole-star (*when iron was kept away from it*), the confidence of sailors in their compass was strengthened. Ships began to be enlarged, improved in form, and more efficiently rigged. They were made to hold better store of necessaries; to shape direct courses from one port to another; and, leaving the land behind, to cross seas, no longer considered dangerous. The new mariner's compass called into existence other instruments used for determining a ship's position at sea; sea-charts and sailing directions were soon required; handbooks were published for the use of seamen, and the art of navigation advanced rapidly. Adventurous mariners of every European nation sailed out in search of new discoveries. The Venetians proceeded northward and discovered

Greenland. The Normans fell in with the Canary Islands. The Portuguese, who were the first great examiners of the ocean, discovered the Madeiras and the Azores, or Western Islands—penetrated the Torrid Zone, and examined the Gulf of Guinea.

10. An ordinary ship's compass consists of a small magnetized bar of steel, balanced at its centre on the point of a vertical support. To the upper side of this bar, called the *needle*, is attached a circular *card*, the circumference of which is divided into thirty-two equal parts called *points*, each mark of division, which is also called a point, having a particular name; those marked N. S. E. and W. are called cardinal points, and the names of the others, which may be learned from the representation given at p. 370, are compounded of these four letters. On the outer rim of the card are marked the 360° of the circle, so that each point must include $11\frac{1}{4}°$: the points are divided into *quarter points*. In fixing the card, care must be taken that the line joining N. and S. must be in the true line of direction of the magnet; they will then, when the needle turns freely, point *towards* the north and south points of the heavens. In the inside of the box, in which the needle with its card is balanced, are two marks exactly opposite each other, that is, 180° apart, and for use on board ship the compass must be so placed that these shall be in the direction of the ship's length from bow to stern. Since the point N. is constantly towards the north, as the ship's head turns, different points of the card will stand opposite to the mark of her line of length, and in any particular position the point of the card opposite the mark will tell the direction in which the bow points. The helmsman can therefore see in what direction he is proceeding, and by management of the rudder and sails can place the ship's head in whatever direction he is ordered, and keep it so.

11. To prevent the needle from being thrown off its support, there is inserted in the middle of it a small brass cone, the top of which, to diminish friction, is

formed of agate, and in this the point of support can play without the possibility of its slipping off. And to preserve the horizontal position of the card during the heavings of the ship, the compass-bowl is made with a heavy bottom, and swung by two pivots from a brass rim, which rim is itself also swung in like manner, but in an opposite direction from the fixed supports. Thus, if the bowl plays backwards and forwards, the rim plays from right to left. By this contrivance, called the *gimbals*, a kind of universal joint is formed, by which the compass-bowl swings freely in every direction, and so secures the horizontal position of the card, notwithstanding the motion of the vessel.

12. Were the free magnet, upon which its indications depend, invariably directed to the same point of the heavens, nothing could form for seamen a more infallible guide than the mariner's compass. Unfortunately it scarcely ever does indicate the true north, and, therefore, invaluable as it is, requires much caution in its use, and allowance for errors when they are ascertained. The sources of error in the compass may be classed under (1) those which arise from the magnetism of the earth; (2) those which are due to its position in the ship and the consequent action of exterior influences; and (3) those which result from errors of construction.

As an artificial magnet freely poised, the compass-needle is subject to two kinds of deviation from the north point of the heavens—one horizontal and the other vertical; these are called *variation* and *dip*.

13. VARIATION OF THE COMPASS.—During Columbus's outward passage in search of a new continent, he observed a very extraordinary change in the mariner's compass of his vessel. Whilst sailing westward, with the N.E. trade wind on the 14th of September, 1492, he discovered that *the north-point of the compass-needle no longer pointed towards the North Polar star*. This discovery greatly alarmed Columbus's seamen, for an erroneous opinion had till then been entertained,

not only by seamen, but by almost everybody, that the compass-needle was attracted by, or pointed to, a *fixed point in the heavens*, and that the earth itself did not attract the compass-needle at all. The crew became disobedient and mutinous, firmly believing that as the compass-needle proved "untrue to the Pole" they would never be able to return home. Columbus managed to calm their fears and command their services; but on his return to Spain, when he made a statement about the "Variation of the Compass," he had the mortification of being regarded as a romancer—his account was regarded as devoid of truth, because the very instrument he had used in the West Indies resumed in Spain its polar pointing. This *variation of the compass* is now a well-ascertained fact. Every ship that sails from Lisbon, or San Lucar, to the West Indies in 1858, will find a similar gradual change in the direction of its compasses, which will amount to 24 degrees.

14. The needle of the mariner's compass is, like all other freely-supported magnets, subject to two sets of variations—one from *change of place*, and the other from *lapse of time*, besides a number of sudden alterations of direction from *magnetic storms*, the laws of which are not yet investigated, but which, being transitory in their influence, are not of much practical importance. First, as regards *place*: there are lines, or rather one great irregular curve passing through the magnetic poles of the earth, at which alone the needle points truly north; these are called lines of no variation. In all other longitudes the needle departs from the north, increasing in amount of error as we recede from the magnetic meridian, as this line is called, until it reaches a maximum, and then decreasing as we approach the opposite meridian. This variation amounts, when greatest, to as much as 24° 41′, so that at some places the direction of the needle is really north-west or north-east instead of north.

15. It might be supposed that when once the lines of equal variation, called isogenol lines, have been ascer-

tained and marked upon a map, the mariner who knew his position would know the allowance to be made for compass error; but a new difficulty arises from the fact, that these lines of no variation shift their positions upon the earth's surface, and consequently the variation at every place changes with *time*. Thus, in London the declination was, in the year 1580, 11° 15′ to *the east;* in 1660, it was 0°—*i. e.*, the line of no variation had moved over London; in 1818, the declination amounted to 24° 41′ *west:* since which time the magnetic meridian has been moving back again towards the east, and the declination consequently diminishing. It has been estimated that the rate of decrease at present is about 5′ annually.

16. Dip.—In the year 1580, an English compass-maker made a new discovery in compass-needles, of very considerable importance to the ultimate advancement of science. Mr. Norman found that, however carefully he made his compass-needles and *card* to rest upon their pivots in a horizontal position, the moment he magnetized the needles their horizontality was destroyed; and in order to restore it, he had to superadd bits of lead or wax to the south arms of the needles, or semicircle of the card. Mr. Norman, being an ingenious man, made a needle with an axis passing through its centre of gravity, and having magnetized it, it pointed in the direction of the magnetic meridian, but 72′ below a horizontal plane. Mr. Norman's discovery was published; *dipping-needles* were made, and experiments tried in different parts of the world. A dipping-needle is a magnetized bar of uniform size, accurately poised on its centre of gravity, with a graduated circle to mark the declension from a horizontal position. It was ascertained that needles suspended in this way settled in a horizontal position near the Equator, but dipped or pointed downwards, on approaching either Pole. It was by means of these instruments that the position of the magnetic equator was traced, and the latitude and longitude of the magnetic poles of the world marked out on our maps.

17. In any part of the world whatever, a dipping-

needle would point out *where* the induced poles of any article of iron may be found in any position whatever of the iron. The *magnetic equator*, which does not coincide with the equator of the earth, has been traced by observing the places at which the dipping-needle remains horizontal: in other words, it marks out a line upon the earth's surface where there is *no dip*, as we before spoke of a line of no variation. The dip of the north or south pole of the needle increases as we advance from this equator, and at the north or south magnetic pole of the earth it becomes nearly perpendicular.

18. MAGNETISM OF A SHIP.—We have said that the earth is a large magnet, and gives out magnetism to substances by a process called induction, dependent mainly upon the capacity of the substance for the reception of magnetism, and the relative position of the substance, and the direction of the earth's magnetic force shown, by the position of the dipping-needle, would assume at any particular place.

19. There is really no inconvenience arising from the induced magnetism of iron applied on shore to structures, of any kind. But when iron is introduced into ships' cargoes, or as fastenings in the hulls of sea-goingvessels, or when ships are built entirely of iron, and half rigged with the same metal; and have to be conducted through shoals and rocks, and across trackless seas, the magnetism of ships and their contents presents a subject for grave consideration; for the magnetism of a ship and her contents is incessantly changing in polarity as the ship moves from place to place—alters her course, heels from an upright position—pitches, rolls, or rocks from side to side, with every change of wind, or condition of surrounding waves. The polarity of the iron moves from end to end, or from side to side in the ship, as rapidly as air-bubbles would shift positions in spirit-levels, if laid on a ship's deck in stormy weather; because although the ship and her contents may preserve constant relative positions, yet their position relative to the direc-

tion of the *magnetic line* (line of dip) are constantly undergoing changes. Let the reader imagine a thousand artificial magnets, suspended by strings to the beams and sides of a ship under sail, and rocking about by the action of the winds and waves: let him consider how a multitude of unequal magnets thus suspended, and dangling about, would act upon a steering compass within the vessel—he cannot even guess at what would be the result of their action on a compass. In one of our wooden three-deckers there are at least a thousand tons of iron in guns, tanks, ballast, shot, cables, knees, bolts, and bars; and probably ten thousand separate articles of iron: every one of these is an induced magnet by position, and exercises a magnetic influence to distract a magnetic needle within the vessel. In iron ships, and ships laden with iron, the compass is subject to a local magnetic oscillation, altogether independent of mechanical construction.

20. You may easily exhibit this kind of vibration, thus:—Place a pocket compass on a table, and let the needle come to rest; then take a piece of iron bolt or bar, and hold the iron directly over or under the compass, in a horizontal position, and east and west direction: in this position the compass will not be disturbed: incline the iron 8 or 10 degrees, and the compass will deviate: incline it from side to side, and the compass will oscillate, and demonstrate the kind of magnetic disturbance we are discussing. M. Arago found that the vibrations of a magnetic needle were greatly diminished by being placed within a thick copper ring; but it has been found that these rings, when applied to *sea compasses*, do not prevent the oscillations that are necessarily kept up, so long as the ship continues in motion. The error of a compass from the aggregate action of the iron in a ship, will necessarily be the resultant of all the separate forces acting as disturbing or compensating agencies. The actual amount of magnetism in ships, and the resulting compass deviations, may be found by turning the ship round from point to point, and taking a

regular succession of compass bearings of some distant object, whose correct magnetic bearing has been predetermined: we have only to compare the correct bearing of the object, when the ship's head was on each separate point; and thereby obtain a table of corrections for each course the ship may steer.

21. Although a short essay may serve to draw the reader's attention to this important subject, yet our present limits do not admit of going far enough into the rather complicated conditions, resulting from the induced magnetism of a ship, and the ever-varying disturbance which that magnetism exerts upon the steering compass, by causing it to deviate from the correct magnetic meridian, to save a navigator from error, if he does not clearly understand the principles of his art.

22. An iron sailing ship, named "W. S. Lindsay," sailed from London with emigrants for Australia: she had been carefully swung round in an upright position, in order to determine her compass errors, and had these errors ascertained or corrected; but no observations or experiments were made to detect the errors that might be caused by the ship's inclination under sail. In proceeding from the Thames towards the Downs, the pilots observed that when the ship inclined 10 or 11 degrees on the port tack, and was actually making an E.S.E. course, the compass indicated a S.E. by S. course! showing an error of 33° 45′, arising from a change in the magnetic condition of the ship, produced by her inclination from an upright seat in the water. These facts were made known to her owner, who at once recalled the ship to the river, and thereby prevented all chance of calamity to the ship and passengers.

23. Another iron sailing ship, larger than the "W. S. Lindsay," sailed some time after from Liverpool with emigrants. It seems that in this case also the compasses had undergone some kind of correction, but whilst the vessel was on her way towards Holyhead, the pilot observed that the compasses, of which they had several, did not agree. Her sail was set, with a

southerly wind, and the ship made several stretches between the island of Anglesey and the Irish coast. Unfortunately the captain, like many other seafaring men, considered that *one* of his compasses was correct, and that all the others must necessarily be wrong. He accordingly recorded his courses, and computed the ship's position from this particular compass. The ship's "departure" was taken from the Skerries light near Holyhead: the courses as indicated by the compass, considered to be correct, were in a south-westerly direction, and down the Irish Channel to a position twenty miles to the eastward of Wicklow Head. The captain, whose life was preserved, gave this evidence, and so confident was he of his reckoning, that he abstained from taking soundings to verify it.

24. The ship, the "Tayleur," had been standing on a wind on the port* tack (inclining to starboard) for 12 or 14 hours after the *departure* was taken, when land was dimly seen to leeward and at no great distance, the weather being hazy. Everybody was alarmed: attempts were made to *wear* the ship, and then to tack her, but without success. The anchors were hastily let fall, and reached the bottom, but the chain cables snapping, the fated ship drifted on the rocky cliffs, where her iron bottom was bilged, and her water-tight compartments filled. The waves now broke over her with overwhelming fury, and in a short time she slid down the rocky incline, and sank in deep water, drowning 290 persons—an awful calamity, arising entirely from the magnetism of the ship being disregarded, or very imperfectly understood.

25. The survivors who reached the shore found themselves on "Lambay Island;" so that, instead of the ship having made a course down the Irish Channel, she had been going *directly across it.* The course which the compass indicated will, on computation, be found to differ

* Port means the side at the left hand of the helmsman and starboard that on his right; a ship is said to be on the tack from *which the wind comes.*

four points from the actual direction the "Tayleur" went from her position of the Skerries to the place where she struck the shore. Judicial and official inquiries have been held on this deplorable wreck, and from the evidence obtained, it appears that the "Tayleur" was wrecked by being insufficiently manned—by neglect in the officers in not taking soundings—but principally in consequence of the magnetism of the ship in her inclined position, causing the compass to deviate from its correct meridian, against which errors no sufficient precautions had been taken. The reader may probably be surprised to hear that the number of persons drowned by the wreck of the merchant ship "Tayleur," was greater than the number of men and officers killed in any one of the great battles fought and won by the British fleets at Algiers, Camperdown, Copenhagen, the Nile, or on the 1st of June, 1794, when Lord Howe gained a victory in the broad Atlantic.

26. To guard against such casualties, all her Majesty's ships, when put into commission for service at sea, are "swung" for the express purpose of ascertaining the ship's local attraction, of which a record is made in a tabular form: and when vessels proceed from station to station the operation is repeated. By a clause in the Mercantile Marine and Steam Navigation Acts, also, certificates are required from the owners of sea-going steamers that these vessels' compasses have been "properly examined and adjusted;" but this salutary regulation is not enforced with sufficient stringency, and does not extend to sailing vessels of any kind, even although laden with iron, or merely built of that metal.

27. The magnetism of ships was observed as far back as the year 1680, by Dampier, a seaman of great penetration, who found, on making observations of the errors of the compass, that they varied among themselves with the ship's head in different directions; similar results were afterwards noticed by Captains Cook, Flinders, Scoresby, and many others. In the Royal Navy, compass errors are now ascertained by

competent persons, and young naval cadets are required to prepare for being examined on magnetism before they receive commissions. In the mercantile marine, also, masters and mates must be examined and qualified, and the examinations are doing much for improving the professional acquirements of the candidates. It is, however, in our nautical schools that sound professional education is obtained, and the principles of mechanics, navigation, and practical magnetism demonstrated. The young students of nautical science may, by a careful reading of text-books, and attention to the instructions, explanations, and oral lectures of their able masters, soon acquire an education far surpassing that of the celebrated Captains Dampier or Cook, who never enjoyed such advantages. Young men should avail themselves of the facilities thus open to them, and acquire the knowledge requisite to qualify them for commanding and navigating our ships in every quarter of the world, with credit to themselves and advantage to their country.

28. In Columbus's time, and even two hundred or three hundred years later, seamen regarded their compass as the most important of all instruments. With compass well cared for, a log-lead and good look-out, and a few very imperfect instruments, the old navigators went carefully and cautiously through seas, but very imperfectly known. But as other instruments were invented, such as the quadrant, sextant, and chronometer, the mariner's compass became of less importance in the eyes of unthinking men, content if they could, every day or two, find their ship's position at noon by an observation of the sun. But as these important improvements in navigation were made, new uses were discovered for iron in ships, and the art of keeping correctly what is called a ship's *reckoning*, became more difficult and dangerous, by reason of the magnetism of the ship affecting the compass. In long voyages across the ocean, where hidden dangers are few and far between, there is little difficulty in navigating

ships, and finding their latitude and longitude by actual astronomical observations, in sunshine and clear weather; but these advantages to navigation can never be a guard against the evils resulting from compass errors, and the ship's "local attraction."

During the time that elapses between two consecutive astronomical observations, a ship is steered by means of the compass, and the *dead reckoning* is computed from the recorded compass courses; so that in cloudy or foggy weather, when observations cannot be taken, the mariner's compass must necessarily be his only guide; it must still be, as it was of old, "the leader," "the conductor," and "the stone of enterprise."

29. When ships of war sail together in fleets under an admiral, or, when merchant vessels sail under protection of a man-of-war, the commanding officer makes a general signal for all the ships to steer a certain course during a fog, or for the night, in order that the ships may "keep company." If all the compasses in the fleet were correct and without deviation, the ships would keep their stations in a fog; while, if they all differed by local influences, the ships would disperse and part company in foggy weather. It is, therefore, incumbent on a mariner to use all possible means for acquiring a knowledge of a ship's magnetism and the errors of her compass. If he cannot actually determine the exact amount of error, he may, at all events, ascertain the *direction* in which his ship is likely to deviate from her intended course, and guard against danger.

30. The Lords Commissioners of the Admiralty, about thirty years ago, issued an order to the Dockyards, that no iron whatever should be placed within a distance of fourteen feet of the steering compasses, but by more recent orders the distance has been reduced to 7 feet, a distance, in my opinion, too small. When two compasses are used on the same deck, they are required to be 4 feet 6 inches apart, in order to be beyond their sphere of mutual disturbance.

31. ERRORS OF CONSTRUCTION.—A powerful com-

pass-needle, mounted in the ordinary way, and attached to a very light card, is found to be very useful in fine weather and smooth water at sea; but almost useless in a rough sea, by reason of its oscillations; whilst a weakly-magnetized needle, attached to a heavy compass-card, is found inert and unfit for steering a ship in smooth water and fine weather, but pretty steady in a storm. We have stated how Mr. Norman discovered the dip of the needle in 1580, and that counterpoising weights were required to keep the needles in a horizontal position. These weights are still used, and are actually measures of the magnetic intensity of the needles to which they are attached: the weights must be proportional to the magnetism of the needles they counterpoise. All compasses are thus weighted, and although the neat pocket compasses, so convenient for experiments, and so easily procured, generally have naked needles balanced on their pivots, apparently in equilibrium and without *weights*, yet there is always more metal in the S. arm than the N. arm. When a ship is tumbling about among the waves at sea, both arms of her compass-needle are moved with equal velocities through the air; but we have seen that the quantities of matter in the arms *are made unequal*, and when multiplied separately by one common velocity or motion, their products will be unequal; and hence it must follow from mechanical laws that the moving with a common velocity, but having unequal momentums, must cause constant compass oscillations, when a ship rolls or pitches. The vibrations arising from constructive mechanical errors were constant sources of annoyance to mariners; very many remedies have been tried, such as by adding weight to the card, or, what amounts to the same thing, taking away magnetism from the needles. One very fair remedy had been applied, namely, filling the compass-bowl with rectified spirits of wine, and thus partially floating the needle and card in the liquid, as the Saracens did of old on the coasts of Asia Minor. But a remedy recently tried, greatly *increased* these inconvenient compass oscillations. To a single compass-card,

delicately suspended, from 4 to 12 parallel needles were attached, thereby increasing the evil in an arithmetical ratio, and rendering the compass useless in a gale of wind!

32. We shall conclude this brief article upon a very important subject by referring the reader to a valuable pamphlet by A. Smith, Esq., published by the Board of Trade, containing an account of the modes by which, whenever an opportunity offers, the error arising from the ship's attraction may be found, so as, when tabulated, to give the corrections which ought to be applied in various positions of the vessel.

WILLIAM WALKER.

Fine Arts.

ORNAMENTAL STYLES.

BY R. W. WORNUM.

LESSON I.

ANCIENT STYLES.

INTRODUCTION.—1. There is more in the understanding of the distinctions of ornamental styles than might be at first imagined. It is the comprehension of the tastes characterizing various times and people; and these tastes lay open an essential quality of the social character of these different people in relation to general culture and religion as well as to the arts.

The history of art shows two great classes of style—the symbolic and the æsthetic. We term those styles symbolic in which the ordinary elements have been chosen for the sake of their significations as symbols of something not necessarily implied, and irrespective of their effects as works of art, or arrangements of forms and colours: those that are composed of elements *selected* solely on principles of symmetry and harmony, and exclusively for their effect on our perception of the

beautiful without any further extraneous or ulterior aim, are termed æsthetic.

2. The principal historic styles of ornament, including only such as may be assumed to have had some influence on European civilization, are nine; of these three are ancient, three mediæval, and three modern. Most of these great historic styles, however, have their varieties, that is, the same characteristic elements, appearing in new combinations and slightly modified; but in a classification of styles of this character it is sufficient to explain the broad distinctions, the specific varieties need be simply named.

3. The broad divisions then are — the Egyptian, Greek, and Roman, ancient styles; the Byzantine, Saracenic, and Gothic, medieval styles; and the Renaissance, Cinquecento, Louis Quatorze, modern styles. Several of these styles have their recognized varieties: of the Greek there are the Doric and the Alexandrian, that is, the simple and the florid. Of the Byzantine, there are the Romanesque, Lombard, and Norman varieties; and of the Renaissance also there are several varieties: we speak of the Renaissance as an epoch and as a style, and as an epoch it comprises the Trecento, the Cinquecento, the Renaissance, the Elizabethan, the Louis XIV., the Louis XV., and the Rococo, the two last being varieties of the Louis XIV.; all of these will be fully explained in their proper place, only it is necessary at starting to point out the distinction between a style and a variety.

4. Style is only another name for character, every style as such depends upon what is peculiar to it, not upon what it has in common with other styles: these peculiarities are what are termed *characteristics*, the features by which a style is distinguished. It does not follow, therefore, that an ornamental work is in a certain style, because it belongs to the period of that style, as a style is defined by the peculiarities and not by the date of a period, and it does not follow that every work of a period must possess these peculiarities; while, therefore,

a genuine example of a style will *always* imply a certain time, a specimen of a certain date will only *sometimes* illustrate a style.

EGYPTIAN ORNAMENT.—5. The earliest style of ornament we know anything of is the Egyptian; dating from about 1800 years before the Christian era, when it was already completely established, it must therefore belong also to a much remoter period. As a rule the elements of Egyptian ornament have a particular meaning, they are not often, if ever, chosen for the sake of beauty of effect; hence we speak of the Egyptian as a symbolic style: its elements are almost strictly coloured hieroglyphics, or sacred gravings, derived entirely from a priestly symbolism. The fundamental basis, however, of all ornamental work—a symmetrical arrangement—is thoroughly displayed in the schemes of Egyptian decoration, though they seldom extend beyond the most simple progression, either in a horizontal line, or repeated on the principle of the diaper, that is, row upon row, horizontally or diagonally: the painted ceilings of the tombs of the Kings at Thebes afford many good examples of the diaper.

6. In many respects ornamental art was as thoroughly understood at Memphis or at Thebes 3000 years ago as it is at London or Paris to-day. The shapes of the Egyptian ewer and basin, and other vessels for domestic purposes, are nearly identical with those of the most favourite patterns of the present time: and many of their ornaments are still popular, and have been so through all times, as the zigzag, the labyrinth or fret, the spiral, the wave-scroll, the star, besides the water-lily, or lotus, the papyrus, palm, and many other of the natural productions of Egypt.

7. The frieze, or broad band, is the commonest form of these decorations, and the progression is generally of the simplest character, and composed of simple elements. Beyond the mere band and the covering of the whole surface, on the principle of modern diapers, there is little development of the ornamental art. Even of the

wall pictures of the Egyptians, whatever may be introduced into them, figures in repose or action, battles, sports, or other social scenes, the best examples are but intelligible representations, mere elevations or diagrams. But richness both of colour and material—gold and silver, ivory, and precious stones are essential characteristics of Egyptian taste.

8. The extent of decorated surface in Egypt is enormous, nearly every ceiling, wall, and pillar displays its coloured hieroglyphs, nearly all of which have been carved, that is in sunk relief, before they have received their final decoration in colour. And as this vast scheme of decoration displays little more than an engraved and coloured record, we necessarily find many forms repeated, some much more often than others, which accordingly prominently distinguish these works, and constitute the characteristic elements of Egyptian decoration. These elements are the zigzag, the wave-line, the labyrinth, the lotus, the papyrus, the winged beetle, the asp, and the cartouche. These are mixed up with many others, all of which are symbols, addressing the mind in the first place, and our faculty for perceiving the beautiful in the second only.

9. All these symbols have necessarily their significations, but for the want of exact traditions they cannot now be absolutely ascertained: they have accordingly been variously interpreted, but some significations are palpable. In Egypt it may be said, in comparison with our own country, never to rain, so that the Egyptian nation owed its existence to the Nile, and it is not remarkable that some symbols and much decoration express a species of Nile worship, as the zigzag and lotus more particularly.

The zigzag is the symbol of the Nile, or water, and it is still preserved as such in our zodiac sign of Aquarius, or the water carrier; all water and liquids from vessels, are represented by zigzags. The wave-scroll, so called by the Greeks from its resemblance to the surface of water disturbed by the wind, may have

the same signification. The explanation of that more complicated right line series—the fret, is that it had reference to the labyrinth of Lake Moëris, typical of some of the most important dogmas of the Egyptian religion, more especially the doctrine of the transmigration of the soul. The nymphæa lotus, the blue water-lily of the Nile, a constant ornament in decoration and in manufactures, is another type of the Nile, but more especially of its periodical inundations to which Egypt directly owes its fertility, and as such is the harbinger of the coming abundance; the papyrus is another similar symbol.

There is, however, one particular ornament which is more common and more characteristic than all others in Egyptian decoration—this is the winged globe, sometimes called the scarabæus, or beetle, from its resemblance to that insect in some of its forms. This ornament, which is explained as a species of talisman or charm, as the invocation of the good spirit, or good fortune, Agathodæmon, exists in almost all sizes, and in all mateaials, in relief and in the flat, or in sculpture and in painting. The globe is supposed to represent the sun, the wings providence, and the two asps, one on each side of the globe, dominion or monarchy; in other words the creative, protective, and distributive powers, implying *order*, the *kosmos*, or world of the Greeks. It generally occurs over doors and windows, in passages, and in all central situations of a design, whether architectural, or simply decorative, and in matters of costume.

The swelling asp alone (the cobra di capello), the symbol of dominion, is a very characteristic ornament: we find entire friezes and borders composed of a mere succession of these asps; and it is very common to find them arranged also in symmetrical opposition, one on each side of the cartouche, or shield, enclosing the hieroglyphic name of a king.

The cartouche itself, generally a simple outline resembling an ellipse, enclosing hieroglyphics, is also one

of the most essential elements of Egyptian decoration. To recapitulate briefly, these elements are the zigzag, the wave-scroll, the fret, or labyrinth, the lotus, the papyrus, the winged globe, the asp, and the cartouche; mixed up with many other arbitrary geometric designs, and the great majority of the vegetable productions of Egypt.

10. From the above details it is evident that the Egyptians anticipated the Greeks in some of their most popular elements; their temples also display a great diversity of pillars, from the mere fluted columns of Beni Hassan, to the gorgeous varieties of Thebes, Philoë, and Denderah. But though the Egyptians systematically varied their pillars, so that as a general rule, similar designs for capitals occur only in corresponding pairs in the same colonnade, so that there will be half as many distinct designs as there are capitals, their *orders*, to use an established term, may be reduced to three; namely, the truncated lotus-bud, the lotus-bell, and the Isis-head. The lotus-bell capital exists in a great number of varieties, the distinctive feature, however, being often in the ornamental accessories only, and sometimes in the merest details, as the grouping the lotus-flower or the papyrus, or simply in the arrangement of the hieroglyphics. Where the Isis head is used, all pillars are the same in their main features. The truncated bud is considered the oldest form of the capital, the bell form belongs to the middle period, and the Isis capital to the most modern. In all cases the abacus surmounting the capital is the width only of the pillar, being invariably narrower than the capital, which is of great value in the expression of stability; the great features of Egyptian architecture are breadth and massiveness, with brilliancy of colour.*

11. The Egyptian style of decoration was not without its influence on those nations connected with

* Abundant examples of Egyptian art are given in the works of Sir Gardner Wilkinson, Rosellini, and the French Commission organised by the Emperor Napoleon.

Egypt by the ties of commerce or of conquest. Its influence was great with the Jews, the Greeks, and more especially the Persians, after the plunder of Thebes by Cambyses, 525 B.C., who carried away a colony of Egyptian artists back into Persia. We still see the remains of their influence at Persepolis: and the so-called Nineveh sculptures, recently deposited in the British Museum, are identical in style with those of Persepolis, the work of this Egyptian colony introduced by Cambyses at the close of the sixth century before our era:* the bull figures chiefly in these sculptures, as he does in Persian mythology.

The earliest date that can be assigned to the so-called Nineveh sculptures is the seventh century before our era; the oldest name recorded is, that of Sennacherib, who was murdered by his own sons in 711 B.C.; and as his achievements in Judea in 713 are recorded, the sculptures are evidently since his time. They are from three places, Khorsabad, Kouyunjik, and Nimroud, too remote from each other to have ever constituted a single city. It is impossible to overlook the striking similarity between these sculptures and those of Persepolis, the date of which is sufficiently fixed.

Darius Hystaspes, who succeeded Cambyses, in 521, had been with that king in Egypt, as one of his body-guard, and he was apparently the real builder of Persepolis, though portions were added by Xerxes and other later monarchs. Darius appears also to have been the builder of the palace of Susa. He is perhaps the most distinguished of the Asiatic sovereigns for his architectural works: he carried on extensive works in Egypt, rebuilt the temple of Jerusalem (514 B.C.), and made himself a summer palace at Ecbatana: may he not have extended his love of repairs as far north as Nineveh? The arrow-headed inscriptions are also at Persepolis; and some of the singular figures at Nineveh are found on Darius's own tomb at Nakshi Rustam.

* See Layard's "Monuments of Nineveh," and Ker Porter's "Travels in Persia," &c.

The difference of dialect in the inscriptions would result, of necessity, from the difference of locality and writers.

Nineveh had been destroyed nearly an entire century when the works of Darius were executed at Persepolis; Nineveh therefore cannot have been their model.

GREEK ORNAMENT.—12. The next great historic style we have to review is the Greek, and we find no less a change in the general character than in the details, in this first European style, when compared with the art of Egypt or of Asia. In Egypt we find grandeur of proportion, simplicity of parts, and splendour, or costliness of material—gold, silver, and ivory, precious stones and colour. And we find throughout that the great prevailing characteristic of Asiatic art is sumptuousness: we have it, equally, in the tabernacle, in the temple of Solomon, apparently quite Egyptian in its style, in the works of Semiramis and of Nebuchadnezzar at Babylon; and in the palaces of the Persian kings.

Jewish ornament altogether, like the Egyptian, appears to have been purely representative: the only elements mentioned in Scripture are—the almond, the pomegranate, the palm-tree, the lily or lotus, oxen, lions, and the cherubim (described in the vision of Ezekiel).

The most characteristic feature of Hindoo art seems to be the fantastic, and though possessing the same jewelled richness as the Egyptian, it wants its simplicity and grandeur: its most striking peculiarities are fantastic animal devices, and a profusion of minute foliage. Most Indian work, however, is probably modern compared with Egyptian.

13. It is not until we come to Greece, that we find the habitual introduction of forms for their own sake, or for their æsthetic value purely as ornaments; and this is a very great step in art. The first that attract our notice, are those with which we have already become familiar, as symbols in Egyptian art:—the zigzag, the wave or Vitruvian scroll (a succession of spirals in the same position), and the labyrinth, or what is commonly

called the Greek fret. The most characteristic, however, are, perhaps, the *Echinus*, or horse-chesnut, commonly called the egg and tongue, and the *Anthemion*, known in its most simple form as the honeysuckle or palmette, both of which it somewhat resembles, as represented in the Doric antefixes: it is, in its simplest construction, a mere succession or alternation of one or more conventional floral forms. The bead, or astragal (hucklebone), is another early standard, and constantly found together with the Echinus ornament.

14. The architectural features of the Greek are still more distinctive than the ornamental, in a comparison with the Egyptian.

The flat, ponderous, sloping buildings of the Egyptians are both beautiful and useful, in the landscape and climate of Egypt. And just as the rainless heat of Egypt developed the massive flat roofs, so the rainy seasons of Greece rendered the sloping roof necessary, the gable of which the Greeks eventually developed into their beautiful pediment.

The pediment seems to have necessitated another member in the entablature, the frieze, a feature æsthetically more than mechanically necessary; its service is to diminish the apparent weight of the pediment, and to strengthen in effect the entablature.

The only Greek example of a temple without a pediment—the Pandroseium at Athens (imitated in New St. Pancras church)—has no frieze in its entablature.

15. The distinctive ornament of the three Greek architectural orders, as they are termed, the Doric, the Ionic, and the Corinthian, is the capital, or upper ornamental portion of the column. The most ancient, or Doric capital consists of a round flat cushion, and a large square slab, called the abacus, above it: the cushion is called the Echinus, from its being invariably decorated (painted in the first instance) with that ornament. And as this ornament is so constant, the Doric order may be descriptively termed the *Echinus order*; the Echinus is accordingly the principal ornament of

the period; and with it are most commonly associated the astragal, the anthemion, and the fret.

Like the Egyptian, the Greek is distinguished for its broad flat surfaces; even its curves are comparatively flat, being of a parabolic character—a development apparently due to the practice of polychromic decoration: everything was coloured, and high relief, as producing shadows, is antagonistic to the display of colour. The Doric buildings owed almost all their variety of detail to colour.

On the whole, foliage performs a very secondary part in Greek ornamentation, especially of the early period: conventional floriage is more prominent, and there is comparatively a great variety of geometrical forms and combinations, in the diapers and their borders, found roughly indicated in the dresses on the vases; though we find no corresponding variety in the ornaments of Greek architecture. The common architectural standards are, however, those found most commonly both on the vases themselves, and indicated in the costume of their figure subjects: they are therefore generally characteristic standards of Greek taste.

The Doric constitutes a great epoch of Greek art, extending over a period of at least four centuries; and, with the single exception of the Ionian settlements of Asia Minor, prevailing throughout every country occupied or colonized by the Greek race. The most magnificent example of this style was the Parthenon, or temple of Minerva at Athens, completed under the superintendence of the great Phidias, 438 B.C.

16. With the Erectheium at Athens, 409 B.C., may be said to be established a second period of Greek art, the florid or Alexandrian. The so-called Ionic capital has now supplanted the Doric, or, speaking descriptively, the simple Echinus order was superseded by the voluted Echinus order, called the Ionic, because first displayed in the Ionian city of Ephesus. The capital of this order is little more than the Doric, with the addition of four volutes to the Echinus ornamented cushion: the

base was extended and enriched to correspond with the richer capital, and the flutes of the shaft are more delicate and more numerous. The ornamental details are now further enriched, some are made more familiar, as the astragal, and some new ones are added, as the guilloche or plat, which takes the place of the fret in the Doric, the acanthus, and, in a very simple development, the ordinary scroll: throughout, in harmony with the volute, the curve is now much more developed. The acanthus is the distinctive feature of the third Greek order, the Corinthian, so called because first developed in Corinth: descriptively it may be termed the acanthus order, its best Greek example now existing is the Choragic monument of Lysicrates at Athens, built 335 B.C.

In this second period was established the practice of *carving* the ornaments, instead of merely *painting* them, as was the prevailing custom in the Doric period.

There is always a great simplicity both in the details, and in the arrangement of the materials of Greek ornament, it is generally the various elements arranged in simple horizontal series, one row above the other: all purely ornamental forms are conventional, and every arrangement is essentially æsthetic.

ROMAN ORNAMENT.—17. We now come to the third, and last classic style of antiquity, the Roman; this added no new element to the Greek, but elaborated those already established, with almost every possible variety of effect, on a much larger scale, and with all the exuberance and richness of which they are capable. Roman art is therefore still Greek art; it was original only in its own elaboration of Greek materials, and this almost exclusively through Greek artists.

Its uniform magnificence is one of the chief characteristics of Roman taste; its most popular ornamental elements are those best calculated to accomplish this effect: the simpler elements of the Greeks were comparatively neglected, while their richer ornaments were especially elaborated. The ordinary scroll and acan-

thus are kept subdued in Greek work, in comparison with the Echinus, Anthemion, and others; but in Roman work they are the most characteristic elements. It is the same with the three Greek orders, the Echinus, the Voluted, and the Acanthus order: the last, so rare in genuine Greek work, is the most ordinary in Roman. The only Greek scroll (that is a succession of alternated spirals) is the very simple one of the roof of the Choragic monument of Lysicrates: on Roman monuments the scroll, generally enriched with acanthus foliations, abounds; indeed the acanthus scroll is the most characteristic of all the Roman elements. The Echinus, Anthemion, and many other Greek standards are also common, but there is a greater general fulness in the forms of the Romans, their curves are circular, while the Greek are commonly elliptical; and there is a difference in the treatment of the acanthus foliations of the two styles. The Greeks used the *acanthus spinosus* or sharp prickly acanthus, and the Romans the *acanthus mollis*, or soft acanthus, the Brankursine; this gives a greater fulness and richness to Roman work: they had also a conventional acanthus leaf, called the olive-acanthus, from the leaves looking like clusters of olive leaves: this gave at a distance greater force to the rufflings or serrations of the leaves. Arabesque scroll-work is also a great feature of Roman decoration. Even the architectural orders have not escaped Roman enrichment: the Composite, the only distinctively Roman order, is a compound of the three Greek orders —the Echinus, the Voluted, and the Acanthus, in one.

The acanthus in every form, except in the capitals, is so peculiarly Roman, that its appearance in an ornamental work is alone good presumptive evidence of such work being Roman: the same may be said of the ordinary scroll in anything like an elaborate development.

The free introduction of monsters and animals is likewise a characteristic of Greek and Roman art, as the winged sphinx, always female, the chimera, griffin,

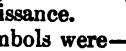
triton, satyr, fawn, and others. They occur, however, much more abundantly in Roman than in Greek work. The most splendid Roman specimens of ornamental art, are those which have been dug up among the ruins of the forum of Trajan, of the early part of the second century of our era: they are the work of a Greek, Apollodorus of Damascus, who may be allowed to hold, perhaps, a similar place in Roman ornament to that which Phidias holds in Greek sculpture generally. Pompeian decoration exhibits the debasement, or rather the vulgar popular development, of Roman taste.

LESSON II.

MEDIÆVAL STYLES.

1. BYZANTINE ORNAMENT.—We may now turn to the middle-age styles, which, in contradistinction to the ancient, the *Heathen*, may be termed *Christian* art.

The peculiar views of the early Christians in matters of art had, before the establishment of Christianity by the state, no material influence upon society, though the pagan idolatries found many bold and vigorous opponents long before the time of Constantine. During the earlier centuries, Christian works of art were limited to symbols, and were rarely applied as decorations, but as exhortations to faith and piety. And all Christian decoration rests upon this foundation: the same spirit of symbolism prevailed throughout, until the return to the heathen principle of beauty, to the æsthetic, in the period of the Renaissance.

2. The early symbols were—the monogram of Christ in several forms, as (); the lily; the cross; the serpent; the fish; the aureole, or *vesica piscis* (fish bladder); and the circle or *nimbus*, the glory of the head, as the *vesica* is of the body. The *vesica* representing the fish is an acrostic symbol, from the Greek word ἰχθυς (*ichthus*, fish), consisting of

the initials of the following sentence,—Ιησους χριστος θεου υἱος Σωτηρ—Jesus Christ, of God the Son, the Saviour. These are important elements in Christian decoration; more especially the *nimbus*, which is the element of the trefoil and quatrefoil so common in Byzantine and Gothic art: the first having reference, as is supposed, to the Trinity, the second to the four Evangelists as the testimony of Christ, and to the cross, at the extremities of which we often find four circles. These are sometimes simple circles, and sometimes they contain the four symbolic images of the evangelists—the Angel, the Ox, the Lion, and the Eagle. Five circles alone, in the form of a cross, have the same signification—they represent the five *nimbi;* that in the centre indicating the Lord, and those at the sides the four Evangelists.

The hand in the attitude of benediction is another element in early Christian and mediæval works of art: there is a distinction between the Greek and the Latin form, the former symbolizing Jesus Christ, expressing his Greek monogram IC. XC by placing the thumb on the third finger, and slightly curving the second and fourth; the latter form, displaying the thumb and the first and second fingers only, extended, symbolizes the Trinity. The Roman prelate blesses in the name of the Trinity; the Greek, in the name of Jesus Christ.

3. Without some knowledge of these essential points, the Byzantine decorations are quite unintelligible, for their early designers would appear to have avoided rather than sought beauty in all these peculiar forms: the principle is exactly the same as that by which Egyptian art was regulated. The lily, too (the fleur-de-lis), the emblem of the Virgin and of Purity, is as common in Christian decoration as the lotus is in that of Egypt. It is the symbol which was eventually elaborated into the most characteristic foliage of Byzantine and Romanesque art; still well illustrated in work of the twelfth and thirteenth centuries, and especially in the old iron-work of that time; conspicuous also in their foliage

is a peculiarly formal and sharp version of the Greek acanthus-leaf, somewhat resembling the ordinary thistle, or holly-leaf. Why the beautiful and accomplished styles of the ancients, therefore, were discarded for such crude elements of ornament, needs no other explanation than that they were Pagan.

Paganism, however, consisted solely in forms, not in colours, and therefore in respect of colour there never was any restriction in Byzantine art. The forms of the ancients, too, as Paganism itself gradually disappeared, were slowly admitted among the elements of Christian decoration; and the scroll, under certain symbolic modifications, became eventually a very prominent feature in Byzantine decoration; and under the same modifications the anthemion and every other ancient form was gradually adopted after a systematic exclusion of about four or five centuries.

4. The very exclusive prejudices of the early Byzantines once overcome, a comprehensive style of ornamental art was rapidly developed. Although they never attained that purity of detail which characterises the works of the Greeks or Romans, still so great was their ingenuity that they made, from their crudest symbols even, very beautiful and attractive designs. In one respect they preserved the ancient practice throughout: all their natural forms were treated conventionally, that is, upon a system of symmetry or symbolism regardless of imitation. This principle applies even to animals and the human figure: every saint had his prescribed colour, proportion, and symbols.* Byzantine decoration was fully matured, and is still shown in perfection, in the rich mosaics of St. Sophia at Constantinople, completed by the Emperor Justinian, 562 A.D.†

5. The leading forms of Byzantine architecture are

* Didron, 'Manuel d'Iconographie Chrétienne.'

† Some beautiful specimens have been lately published in the great work of Salzenberg, on Constantinople, undertaken under the auspices of the Prussian Government.

due to the same symbolic influence: the cross, the circle, and the dome, pervade everywhere. The dome has its own reference to the vault of heaven, whose living glories were generally represented on the spherical roof of the apse at the eastern end of the Greek Basilicas. This representation is known in the Greek church as the Holy Liturgy, or the glorification of Christ; and it often illustrates the dome itself in the centre of the cross. This is the reason that the cross and the dome are so characteristic of early Christian or Byzantine architecture, and indeed of Romanesque architecture generally. Some of the principal Byzantine or Romanesque churches are developments of the symbol of the five circles or glories; they are placed in the form of a cross, and are surmounted by domes corresponding in size and situation with the circles represented in the pavement below: St. Mark's at Venice is a conspicuous example of this symbolic architecture.* This species of architecture, with the dome and round arch, is also termed generally Romanesque, as derived immediately from that which prevailed throughout the Roman empire, at that time, when from heathen it became Christian. Though not Roman absolutely, it is derived from the Roman, and is accordingly *Romanesque*, as implying debased Roman. The word, as a general term, may be universally used to distinguish the round arch species from the pointed arch species,—the Byzantine, Lombard, and Norman, from the Saracenic, Siculo-Norman, and the Gothic.†

6. The Byzantine was so widely spread, and so thoroughly identified with all middle-age art, that its influence did not entirely cease until the establishment of the Renaissance in the fifteenth century: both the Saracenic and the Gothic proceeded from the Byzantine. The Greek missionaries carried its influence into the extreme north; and while the artists of Syria were ac-

* See Kreutz and Salzenberg.

† The Romanesque is beautifully illustrated in Osten's 'Buildings of Lombardy.'

commodating their style to Mohammedan exclusiveness in the south, in the colder regions of Europe the mysteries of Mount Athos were freely mixed up with the fables of Scandinavian mythology.

The Scandinavian soldiers also, of the imperial body-guard, made the talismans of Christian mythology almost as familiar in their native homes as the gods of their forefathers. The same mixture became as common eventually on the portals of Lombardy. The ordinary northern crosses, so conspicuous for their interlaced ornament and grotesque monsters, are apparently modifications of the Byzantine symbol of the Redemption. The serpent figures largely in Byzantine art, as the instrument of the fall, as well as one type of the Redemption. The cross planted on the serpent is found sculptured on Mount Athos; and the cross, surrounded by the so-called Runic knot, is a Scandinavian version of this Byzantine image—the crushed snake curling round the stem of the avenging cross.* There is this difference between the Byzantine and the Lombard and Norman varieties—that the symbolism is mere matter of habit in the two latter, and generally perhaps, though rudely, preserved in many forms, is disregarded in their spirit; that is, in mere ornamental details, such as the zigzag, dog's-tooth, nail-head, star, chain, and a host of others; but the symbolic figures and other religious decorations mean exactly what they express.

As the peculiarly Norman style, such as it is best known in this country, was originally developed in Sicily, it contains, of course, many Saracenic features, of which the pointed arch and the zigzag are the most prominent; for the Norman, though originally a simple Romanesque style, eventually adopted in the twelfth century the pointed arch of the Mohammedans. This style is well developed in the cathedral of Cefalu, built

* Some good examples of these crosses may be seen in Chalmers' 'Sculptured Monuments of Angus,' in the library at Marlborough House.

by king Roger in 1132.* And it is from this Siculo-Norman that both the round arch zigzag style and the pointed transition or lancet style were originally developed in this country.

7. SARACENIC ORNAMENT.—The principles of Saracenic decoration are very simple: the Arabs had no art or artists of their own; they came from their deserts with no more taste or knowledge of such matters than a mere love of finery could give them; and they could not but be struck by the gorgeous display of such cities as Damascus, which fell into their hands in 634 A.D. New ambitions arose with their new power, and the Byzantine artists were pressed into the service of the Arabian caliphs and generals, and ordered to raise rich mosques and palaces: Damascus, Cairo, and Cordova, show the admirable ingenuity with which they accommodated themselves to their new circumstances. The conditions of the new Mohammedan law were stringent; in endless designs in mosaic, marquetry, or in stucco; there was to be no image of a living thing, vegetable or animal. Such conditions led to a very distinctive style of decoration; vegetable forms were now excluded for the first time. However, by the seventh century, when the works of the Saracens commenced, the Byzantine Greeks were already sufficiently skilful to make light of such exclusions; and the exertion of ingenuity to which they were impelled gave rise to a more beautiful simply ornamental style perhaps than any that had preceded it, for there was no division of the artistic mind now between meaning and effect; and although the religious cycles and other symbolic figures which had hitherto engrossed so much of the artist's attention were excluded, the mere conventional ornamental symbolism, the ordinary forms borrowed from the classic periods, and geometrical symmetry, left an abundant field behind, which was further enriched by the peculiarly Saracenic custom of elaborating inscriptions among the details of ornamental designs.

* See Gally Knight's 'Saracenic and Norman Remains in Sicily.'

8. Mere curves and angles, or interlacings, were now to bear the chief burden of a design, but distinguished by variety of colour. The curves, however, very naturally fell into the standard forms and floral shapes, and the lines and angles were developed into a very characteristic species of tracery or interlaced strap-work very agreeably diversified by the ornamental introduction of the inscriptions. And although flowers were not palpably admitted, the great mass of the minor details of Saracenic designs are composed of flower forms disguised; the very inscriptions are sometimes thus grouped as flowers: this is especially the case in the later works of the Alhambra. Still no actual flower ever occurs, as the exclusion of all natural images is the fundamental principle of the style in its purity.

9. One of the greatest works produced under these circumstances was the magnificent mosque of Touloun at Cairo, a monument of the ninth century, 876 A.D, and the recorded work of a Greek. Its ornaments are in stucco, and altogether offer the most characteristic example of the combination of Byzantine and Saracenic elements: with the Saracenic tracery and inscriptions and other peculiar forms, we have combined several of the most popular ancient ornaments in their Byzantine garb, but somewhat more than ordinarily modified—as the fret, the anthemion, the guilloche, the horns of plenty, and the fleur-de-lis.

10. In all the buildings of Cairo we have the pointed arch, which appears first, I believe, in the great mosque of Amrou, a work of the seventh century, 641 A.D.; the ogee, the crescent, and the scalloped arches, are more characteristic perhaps of Saracenic architecture generally, but the simple round Romanesque arch also occurs in the Moorish works of Spain. This style became gradually richer as it advanced westward from Egypt to Sicily, and especially in Spain, where the Alhambra, a work of the fourteenth century, still remains to bear witness to its unparalleled richness of detail. The Saracenic was the period of gorgeous

diapers, for the habit of decorating the entire surfaces of their apartments was peculiarly favourable to the development of this class of design: the Alhambra displays almost endless specimens, and all are in relief and enriched with gold and colour, chiefly blue and red. Some examples give the idea of being more endurable imitations of the rich woollens of Cashmere, which the Arabs made great store of. The Genoa damasks, Arras tapestries, and modern paper-hangings, are all imitations of these Saracenic wall-diapers. The very word damask implies Damascus work: Damascus was, however, famous for such fabrics before its conquest by the Arabs. It was called Damesk, and was a place of repute even in the time of Abraham. It is still famous for its textile fabrics, in a pure Saracenic taste, and it produces a great variety of patterns in silk and in cotton, the designs of which are still chiefly stripes and inscriptions, good wishes, and pious sentences.

11. The Siculo-Norman, from which our own round zigzag, and the pointed Norman are derived, is as much a variety of the Saracenic as of the Byzantine: it is, indeed, a free combination of the two styles; for the reserved mixture of the two hitherto practised had its Christian character restored to it by the Normans, through the introduction of sacred figures, and a prominence which the artists of that period gave to all the most palpable Christian symbols, more especially the cross, which never occurs in genuine Saracenic works. The new moon or crescent also is equally excluded from Saracenic work, but apparently simply from the accident that it was first adopted by the Turks after the conquest of Constantinople in 1453, as the emblem of their conquest of the Greek capital, of which it was the ancient symbol or crest.

12. Gothic ornament.—We will now proceed to the last great middle-age style, the Gothic. Of this I can only speak as regards its general principles: to explain all its subdivisions would occupy much space. It grew out of the Byzantine, and flourished chiefly

on the Rhine, in the north of France, and in England. It was developed in the thirteenth century, and was perfected in the fourteenth; its most characteristic monument is perhaps Cologne Cathedral, which was consecrated in the year 1322, but is still unfinished. Salisbury Cathedral, the first great work of the kind in this country, commenced about 1221, is a work of the French; it was, however, in style a genuine Norman beginning. In the fifteenth century the style rapidly declined, and it became quite extinct, in this country at least, in the sixteenth, a catastrophe doubtless caused by the Reformation.

13. England has had seven ecclesiastical styles, extending over a period of about five hundred years only, from the death of Edward the Confessor, 1066, to the death of Queen Mary, 1558, when all ecclesiastical architecture ceased; and the Tudor was superseded by the Renaissance, in the reign of Elizabeth.

These seven styles are:—

1. The Saxon, or simple round-arch Romanesque.
2. The round Norman, or zigzag style.
3. The pointed Norman, or transition (Henry II., or first Plantagenet style).
4. The early English Gothic (Henry III., or second Plantagenet style).
5. The decorated Gothic (the Edwards, or third Plantagenet style).
6. The perpendicular Gothic (Henry VII., or Lancastrian style).
7. The debased perpendicular, or rather, horizontal (Henry VIII., or Tudor).

Thus, during the period of the seven Edwards there were seven styles, the duration of each of which was, on an average, about seventy years (1066-1556), the age of a man, so constant and so rapid were the changes. Three only of these styles, the fourth, fifth, and sixth, are what are more strictly termed Gothic. The two first are round, and belong to the Romanesque or

Byzantine varieties; the third, to the transition from the round to the pointed styles; and the seventh is the transition from the pointed styles, in which the arch is so prominent a feature, to the modern varieties of the Renaissance, in which the arch is not prominent, and when it occurs it is round, as in the classic styles of antiquity.

14. The general characteristics of the Gothic as an architectural style are these:—it is essentially pointed, or vertical, in its tendency, and in its detail is geometrical, in its window tracery, in its openings, in its clusters of shafts and bases, and in its suits of mouldings; but it is only geometrical in its construction or in its form, not in its spirit or motive. All the symbolic elements of the Byzantine are continued in the Gothic; there is a close traditional connection between them, though the violence of the image controversy between the East and the West, as well as some other causes, had a very material influence towards the development of a difference of style by the Greek and Latin churches. Climate has, however, certainly had much to do with the peculiar development of the so-called Gothic; it has flourished only in cold regions, subject to much rain and snow; and a simple Gothic structure, with its high-pitched roof, solid buttresses, and narrow doors and windows, looks often very much like a mere fortification against the severity of the weather.

As I have already explained, the pointed arch, one of the characteristics of the Gothic, is not peculiar to it; it had already existed for five hundred years in Egypt, before it was established in the north of Europe; and it is the common form of the Siculo-Norman arch, the original from which our own Transition was derived.

15. The Gothic is chiefly distinguished from the Byzantine, and the Latin Romanesque varieties, by the universal absence of the dome: the union of the belfry with the church is not peculiar to the Gothic, though in most of the great Romanesque examples they are distinct, as at Venice and Pisa; nor are the towers in the place

of the domes peculiar to the Gothic; they are common in the Norman Romanesque, in Sicily, in Germany, and in this country—as at Ely, Peterborough, and elsewhere. The spire is the pointed roof of the tower, and both doubtless originally owed their development as much to use as to ornament; in thinly-populated and only half-cleared countries, such as England was in the middle ages, a spire, or tower, was a landmark performing other useful services besides that of simply indicating the locality of the church, or securing the proper elevation of its bells.

Ornamentally the Gothic is the geometrical and pointed element elaborated to its utmost; its only peculiarities are its combinations of details: at first the conventional and geometrical prevailing, and afterwards these combined with the elaboration of natural objects in its decorations. The Byzantines never did this: their ornaments were purely conventional and traditional; while in the finest Gothic specimens you find, not only the traditional conventional ornaments, but also in the decorated period and in French and German work elaborate imitations of the plants and flowers growing in the neighbourhood of the structures. This is a great feature; but still the most characteristic feature of all Gothic work is the elaboration of its beautiful geometric tracery, vesicas, trefoils, quatrefoils, cinquefoils, and an infinity of geometric varieties besides. The tracery is so paramount a characteristic, that the three English varieties—the Early English, the Decorated, and the Perpendicular—are distinguished almost exclusively by this feature; it is the same with the French *Flamboyant*, so called from the flame-shapes of the spaces of its tracery. The tracery indeed establishes the fact of a style being Gothic or not, for the Byzantine contains only the symbolic foliations—trefoils, quatrefoils, &c., so the transition, or first English pointed style, distinguished by its clustered lancet-lights and so-called tooth ornament, is excluded in the enumeration of Gothic varieties as it has no tracery.

16. The first Gothic in this country is therefore the early English or second Plantagenet style, in which we have the first development of geometrical window tracery; with mullions dividing the lights instead of piers as in the Transition; windows of several lights; flying buttresses; crocketted pinnacles; complicated clustered mouldings, alternately round and hollow; the columns also clustered, and the capitals generally round; an extensive application of foliage, with the trefoil-leaf as the most characteristic ornament, hence called the early English leaf. It is sometimes as formal as a clover-leaf, at other times very irregularly formed, but always with a fulness or roundness of the parts as contrasted with the somewhat similar, but flat or even hollow Byzantine and Norman foliage of which it is a variation. The so-called tooth or dog's-tooth, the most characteristic ornamental detail of the previous pointed style, the Transition, occurs comparatively rarely in the early English, and in the early specimens only, and considerably varied in detail. This ornament was probably, in its original form, simple vesica cross, but, being constructed to fit hollows, was developed into its ordinary character so common in early Plantagenet or Transition work.

17. To the early English succeeded the Decorated, the great style of the fourteenth century in this country, and chiefly characterised by a more magnificent development of the leading elements of the early English, more especially the tracery. The so-called cusping or feathering is much more massive as well as varied in decorated tracery; the whole tracery bar is cusped, while in the previous style the cusping proceeds from the soffit only: these varieties are distinguished as *soffit* and *chamfer* cusping. The Decorated has other original features, the ogee arch, and the pinnacled canopied recesses of the buttresses, and other parts producing a prominence of diagonal lines. The so-called ball-flower and the common serpentine wire-scroll are among the most characteristic details of this period. There is also more nature or imitation in the details than in any other

of the Gothic varieties: but though the general effect is good and extremely rich, the individual execution of the details is uniformily of an inferior quality as compared with the work of other periods.

18. In the third variety, the Perpendicular, the new features are the horizontal line, the panellings, and the substitution of perpendicular for flowing tracery. The most prominent bar of the tracery is the mullion itself, so that the prevalent panelling of the style is also prominent in the window tracery, composed of mullion upon mullion, or mullion and super-mullion, being separated by a horizontal bar, termed a transom. This divides the lights into vertical panes or panels, and the same panelling (of which fan-tracery is also an example) is spread over every surface of the buildings of this period, developing that style which I have termed Lancastrian, commonly known as the Perpendicular: it is the great style of the fifteenth century in this country.

The natural freedom of the details occasionally displayed in the Decorated, is now lost in a formal conventionality in the Perpendicular; which displays an execution of these parts much more analogous to German work, and the original Byzantine elements from which Gothic forms generally were indirectly derived. The crockets also of Perpendicular work are, like the foliage, very formal, exhibiting a square cruciform arrangement in the details of the leaves, and a uniform character more analogous to seaweed than ordinary leaves in the foliage generally; Henry VII.'s chapel, Westminster, is an admirable example of this style.

19. The Tudor is scarcely a Gothic style; the art in it returns to what it was in the Romanesque, and again becomes Horizontal. Its great features are the flat arch, the square dripstone, and the rectangular spandril, a necessary development of the square dripstone over the arch. The running ornament known as the Tudor flower, and conspicuous because almost alone in buildings of this character, is a remnant of the old Byzantine. Its name of Tudor flower is appropriate only in the sense

that it is almost the only mediæval ornament preserved in that style. The original type of this ornament is the old Byzantine alternation of the lily and the cross, common as the decoration of a crown, and for edges or borders of many other kinds.

There are five orders of arches which distinguish these several ecclesiastical styles generally; namely, the round, the pointed, the ogee, the four-centered, and the flat: the *pointed* itself comprising three varieties—the lancet, the pointed, and the drop arch; in the first the pitch being greater than the span at the spring—in the second, equal to it—and in the last, less.

20. The same ornaments that were applied to architecture were applied also, with very slight modifications only, to all manufactures, whether in the flat or in relief. Relief ornaments, whether in stone, wood, or metal, have been nearly identical in all ages. Nearly all our cathedrals illustrate the various architectural styles. Many of them were commenced in the Norman period, and few have ever been completed; but as some progress was made in every period until the final cessation of all such work at the Reformation, each structure shows portions of each style in accordance with the period in which the work was executed. The great majority, however, of our old collegiate and parish churches, comparatively small undertakings, and completed in a single period, exhibit a uniformity of style—the Perpendicular.

LESSON III.

MODERN STYLES.

1. The Renaissance.—Before entering on the description of the individual varieties of the Renaissance, it will be useful to give a general analysis of characteristics of the modern styles. The term Renaissance is used in a double sense; in a general sense, implying a revival of Art, and specially, as signifying a

peculiar style of ornament; that is, implying an epoch as well as a style. The original idea of the *Rinascimento*, or rebirth, which is the literal meaning of the term, was purely architectural. The restoration of classical ornament did not immediately follow the restoration of classical orders, though this was the eventual result. This is rather an important consideration, for unless we bear constantly in mind that the original revival was simply that of the classical orders of Architecture in the place of the middle-age styles, the apparent inconsistencies we shall meet with in the ornamental details of the Renaissance will be apt to confuse us. The Renaissance styles, therefore, are only those styles of ornament which were associated with the gradual revival of the ancient art of Greece and Rome, which was not really accomplished until the sixteenth century, in that finished style the *Cinque-cento*, which is little more than a revival of the best Roman taste.

2. The course of ancient and of modern art has been much the same; both commenced in the symbolic, and ended in the sensuous. The essence of all middle-age art was symbolism, and the transition from the symbolism to the unalloyed principles of beauty, is the great feature of the revival. Art was wholly separated from religion in the Renaissance; but this transition was, of course, gradual.

3. It was in Italy that the new styles were developed. Two distinct schools were flourishing there in the twelfth century; the pure Byzantine at Venice, and the Siculo-Norman in the south, containing all the Saracenic elements, not excluding even the inscriptions. From these, and the introduction of natural forms, wholly irrespective of symbolism, arose a new style, composed almost exclusively of foliage and tracery. This change was due to the gradually increasing influence of the Saracenic, not as an absolute style, but as affording new elements of beauty, especially in its varied and intricate interlacings, which were so very prominent as for a while to constitute the chief characteristic of the new

style, the first step of the transition from middle-age to modern art; known, from its mean time, about the year 1300, as the *Tre-cento.*

The new life and activity displayed by Italy at this period were very much owing to the Latin conquest of Constantinople in the year 1204, which displayed many treasures of ancient art to the Venetians, whose taste was already sufficiently cultivated to appreciate their value; four ancient bronze horses, a Christian trophy of this Venetian crusade, still adorn the façade of St. Mark's.

4. Venice, already rich in Byzantine works, seems to have taken the lead also in the dawning revival of classical art, and the Venetians appear to have contributed more than any others to its most finished development — the *Cinque-cento.* The Venetians, and the Italians generally, controlled by no trammels of tradition, added their own beginnings of natural imitations to Christian or to Pagan elements indiscriminately; the prestige of a thousand years was broken; the classical forms prevailed; and the *Quattro-cento*, the first great style of the Renaissance, was established, and independent art-æsthetics recognised. From this time, the fifteenth century, we have done with all Christian forms and elements in Italy, as essentials in the ordinary details of ornamental art.

5. The great features of the *Tre-cento* are its intricate tracery or interlacings, and delicate scroll-work of conventional foliage, the style being but a slight remove from a combination of the Byzantine and Saracenic, the symbolism of both styles being equally excluded: the foliage and floriage, however, are not exclusively conventional; and it comprises a fair rendering of the classical orders with the restoration of the round arch.

Nicola Pisano, Andrea Taffi, Giotto, and their contemporaries, were the great masters of this style; and the church of San Francesco at Assisi, and the cathedral of Florence, are fine examples of it.

6. In the *Quattro-cento* (1400), the next style, we have a far more positive revival. Lorenzo Ghiberti may perhaps be instanced as its great exponent or representative in ornamental art. Pietro Baseggio, Filippo Calendario, and Antonio Riccio, called Briosco, nearly contemporary with Ghiberti, are likewise important names of this period: they were engaged on the new Ducal Palace at Venice, which is most comprehensive in the character of its ornamental details, in itself thoroughly illustrating the change from Mediæval to Renaissance ornament. The bronze gates of the Baptistery of San Giovanni at Florence, by Ghiberti, exhibit one feature of this style in perfection—the prominence of simple natural imitations, which now nearly entirely supersede the conventional representations of previous times. Nature no longer supplied mere suggestions, but afforded directly exact models of imitation, whether fruits, flowers, birds, or animals, yet all disposed simply with a view to the picturesque or ornamental. The *selection* of the details might still have some typical signification, but this had no influence on the *manner* of their execution, which was as purely imitative as their arrangement was ornamental.

7. In this style also we have the first appearance of *cartouches*, or scrolled shield-work, which became so very prominent afterwards. The oldest example I can refer to is the shield containing the Lion of St. Mark, of about the date 1450, on the watergate of the Ducal Palace at Venice, perhaps by Briosco; and it suggests the idea of the imitation of a sealed parchment or MS. illumination. This kind of decoration certainly seems in some way connected with heraldry. Many of its forms are palpably mere armorial shields, which became very common in the architectural decoration of a later period; and the fact of such forms being afterwards used as mere elements of ornament does not in any way invalidate such an origin.

Another feature of this Quattro-cento style, or Italian Renaissance, is the introduction, for the first time, of

the grotesque Arabesque—in fact, the style of decoration is now of a very complicated character, though not confused; for we still have the Tre-cento interlacings very largely used as borders; and the scroll, from the generally petty serpentine character of the previous style, appears with all the fulness of Roman Arabesque, but not yet very prominently introduced. The classical details and capitals are also now more positively re-produced.

But although, in the Quattro-cento, religious symbolism was generally excluded from the ornamental details, religious sentiment was by no means absent from Quattro-cento art itself; on the contrary, the Quattro-cento is essentially a religious style, but the religious sentiment was transferred from a secondary to a primary object in the design—the actual representation occurs in the place of the mere symbol. As, for instance, in the Ghiberti gates—the History of Moses is the principal subject of illustration of these gates—the ornaments are but the decorations to the several panels. So it is in all other great schemes; there is little decoration but what is merely auxiliary to some religious design. It was not so in the subsequent style, the Cinque-cento; in this the figures and subjects themselves are a mere part, and often a secondary one, of the ornamental scheme.

8. Before explaining the Cinque-cento, the perfect revival or essential *Renaissance*, I will endeavour to explain that more varied combination of elements mixed up with it, and which is commonly known as the Renaissance as a *style:* for I have spoken of the Renaissance as an epoch, and as a style; but it must not be overlooked that the only true or literal revival is the Cinque-cento; the other varieties contain too many original and extraneous elements to be considered an historical revival. The capricious style—the so-called *Renaissance* of the sixteenth century, which was in such good repute with the jewellers—was far more conspicuous for its cartouches, its scrolled shield-work and tracery, than for the more natural or the revived classical ele-

ments of the style; the beauties of nature and the standard ornaments of antiquity could not vie in the general taste, with either the attraction of novelty or the charm of indiscriminate variety, especially with the example of such names as Holbein and Benvenuto Cellini among the advocates of the new elements; but in as far as art and manipulation again attained the ascendency over symbolism, effect over meaning, this style also was a genuine revival.

This third modern style was very general in France, where it was introduced about the time of Francis I., and it is still so great a favourite with the French that French and Renaissance are nearly identical terms. It is remarkably developed at Fontainebleau, also in the remains of the Chateau d'Anet, built about 1548, and other French buildings of that time. The mixture of various elements is one of the chief essentials of this style: these elements are—the classical ornaments; conventional and natural flowers and foliage, the former often of a pure Saracenic character; man and animals, natural and grotesque, and in any combinations; cartouches, or pierced and scrolled shields; tracery independent, and developed from the scrolls of the cartouches; and every variety of jewel forms. The whole history of art does not afford a parallel mixture of elements. It was popular in the Low Countries at the same time: the Bourse at Antwerp (1531) is one of its earliest examples.

9. Our own Elizabethan is a partial elaboration of the same style, probably introduced into England from the Low Countries, the only difference being that the Elizabethan, like that of Henry II. of France, exhibits a very striking preponderance of strap and shield-work; but this was a gradual result, and what we now term the Elizabethan was not thoroughly developed until the time of James I., when the pierced shield even outbalanced the strap-work. The pure Elizabethan is much nearer allied to the continental styles of the time —classical ornaments, but rude in details, occasional

scroll and arabesque work, and the tracery or strap-work, holding a much more prominent place than the pierced and scrolled shields. For the want of better information these features are sufficient to date a building—the tracery or strap-work without the shield-work will indicate the time of Elizabeth; the predominance of shield-work that of James I.; as at Wollaton and Yarmouth, Elizabethan—Crewe Hall and Canonbury House, of the time of James. In Crewe Hall, however, an early work, and attributed to Inigo Jones, the shield-work is not very prominent.

10. Such are four varieties of the revival, distinct from its perfect form, the Cinque-cento: the Tre-cento, the Quattro-cento, the Renaissance, and the Elizabethan. A design containing all the elements of this period is properly called *Renaissance*. If a design contain only the tracery and foliage of the period, it would be more properly called Tre-cento; if it contain, besides these, elaborate natural imitations, festoons, scroll-work, and occasional symmetrical arabesques, it is of the Quattro-cento, the Italian Renaissance of the fifteenth century; and if it display a decided prominence of strap and shield-work, it is Elizabethan. In all these styles the evidence of their Byzantine and Saracenic origin is constantly preserved—in the tracery, in the scroll-work, and foliage, in the rendering of classical ornaments; and, in the earlier varieties, in the shape of the panels containing religious illustrations, which even to the close of the fifteenth century are of pure Byzantine shapes, as they abound in the manuscripts.

The Renaissance is therefore something more approximate to a combination of previous styles than a revival of any in particular. It is the first example of selection that we find; and it is a style that was developed, certainly from a love of the forms and harmonies themselves, as varieties of effect and arrangements of beauty, and not because they had any particular signification, or from any superstitious attachment

to them as ancestral heirlooms. The decorators of the Renaissance were, in fact, the first *artists* in ornamental art since the time of the Romans; they suffered no limits or restrictions but those of harmony or beauty, and whatever may be the varieties of opinion regarding their success, their aim was strictly æsthetical.

11. THE CINQUE-CENTO. We will now proceed to the Cinque-cento (the most important Italian style of the sixteenth century), which as an art development is the most perfect of all the modern styles. The term Cinque-cento does not imply simply sixteenth century art, but this most prominent style which was limited to the sixteenth century, or chiefly developed about 1500, and it is the real goal of the Renaissance, to which all the efforts of the two previous centuries tended. The varieties we have just been examining are but its wanderings by the way, for want of sufficiently conspicuous landmarks. These came at last, through the excavations of ancient monuments, at the close of the fifteenth century, and the style was developed chiefly by the sculptors of the north, and the painters of central Italy. The true spirit of ancient art was only now thoroughly comprehended, and all extraneous elements,—that is, those not of the classic ages,—were gradually excluded. But with such capacities as those of Raphael, Julio Romano, Bramante, or Michael Angelo applied to extricate it from its long entombment, no wonder that it started suddenly into new life, and grew even into a more splendid development than it had ever attained, perhaps, in the most gorgeous Roman period.

12. It would be very ungrateful, however, towards the great Quattro-cento masters to give all the credit of this accomplished style of art to even such names as Raphael, Julio Romano, or Bramante. The efforts of these masters were at first little or no improvement upon the works of their immediate predecessors, the great *Quattro-centisti*—such as Baccio Pintelli, Perugino, Francia, Bernardino Luini, and Pinturicchio; the two last scarcely inferior to Julio Romano himself,

the prince of decorators; and the Lombardi, Agostino Busti, Andrea Sansovino, and other sculptors of the north of Italy may claim perhaps equal rank in their art.

13. The principal monuments of the Cinque-cento in painting are the Vatican Loggie, the Villa Madama, at Rome, the Certosa of Pavia, and the ducal palaces at Mantua. The churches of Venice, Verona, and Brescia afford the best examples of sculpture. The Loggie of Raphael are the arcade of the second story of the court of San Damaso; they were executed about 1515, by Julio Romano, Gian Francesco Penni, and Giovanni da Udine; the last painted the birds and animals—the abundance of which is a very striking feature in the Vatican arabesques.

14. These arabesques of Raphael, said to have been suggested by the ancient remains in the Baths of Titus, appear to have given a great impetus to this style of decoration, for they are the first of their kind on an extensive scale; and even in their character they differ very widely from the Quattro-cento arabesques which were derived from the MSS. and from ancient sculpture, and are very much more formal in their arrangements and detail. However, though the arabesques themselves are of the Cinque-cento character in the exuberance and beauty of the curves and foliations, the entire decorations of the pilasters are far from being of pure style. Copies of these pilasters may be seen at the Kensington Museum.

In establishing a style from examples made with only a general regard to its most prominent characteristics, there is of course much to reject before we have a characteristic illustration of the style; and the Christian symbols, heraldic and other arbitrary forms which we find in Raphael's arabesques must be scrupulously excluded, or the Cinque-cento becomes merged into the mixed Renaissance which led to it, and the distinction of style is lost.

15. The Vatican pilasters, like the designs of Luini

and Pinturicchio, are of a transition character. The Villa Madama at Rome, and the ducal palaces at Mantua, display designs of equal variety of effect, with a greater unity of character in the details. They are the work of Giovanni da Udine and Julio Romano, the same artists who executed those of the Vatican Loggie, but in these later works many of the licences in the Vatican arabesques have been avoided. They are of a more unmixed classical character; the scrolls are particularly fine. Some of the Vatican compositions, from their mechanical absurdities, are purely ludicrous, while the most extravagant designs in the later works are at most fanciful; and, indeed, the grotesque is perhaps the most prominent feature of the Cinque-cento arabesque.

16. The so-called arabesque, that is, the symmetrically balanced scroll-work, is the most characteristic feature of the Cinque-cento: and with this it combines in its elements every feature of classical art in its completest form, with the unlimited choice of natural and conventional imitations from the entire animal and vegetable kingdoms, both arbitrarily disposed and combined. Another of its features is its beautiful variation of ancient standard ornaments, — as the 'Anthemion especially, of which there are some admirable Cinque-cento examples. The guilloche, the fret, and the acanthus scroll are likewise favourites, and occur in many varieties. The Cinque-cento appears, indeed, to be the special province of the curve in its infinite play of arabesque; but in all its developments it is in the form of some natural object or artificial combination. The cartouches and strap-work wholly disappear from the best examples; in all the extensive works in sculpture of the north of Italy, from about 1480 until 1550, such forms are extremely rare; and in defining the Cinque-cento as a style, their exclusion becomes an essential condition. Absolute works of art, such as vases, and implements and instruments of all kinds, are also prominent details of the Cinque-cento arabesque;

but cartouches and strap-work, as unauthorised by ancient practice, are necessarily excluded from the style as a presumed ancient revival, if not on any other principle.

17. The Cinque-cento is considered the culminating style in ornamental art, as presenting the most perfect forms and the most pleasing varieties—nature and art vying with each other in their efforts to attract and gratify the eye. It appeals only to the sense of beauty; all its efforts are directly made to attain the most attractive effects without any intent to lead the mind to a foreign ulterior end, as is often the case with the Byzantine and other symbolic styles, which have frequently solely a religious purpose. The Cinque-cento forms are supposed to be symbols of beauty only; and it is a remarkable concession to the ancients, that the moderns, to attain this result, were compelled to recur to their works. It is only in the contemplation of this consummate style that the term Renaissance becomes quite intelligible; the Renaissance, or re-birth of ornament, is accomplished in the Cinque-cento; still the term is not altogether ill-appropriated to the earlier styles, because these were really the stepping-stones to the Cinque-cento.

This style completely pervaded manufactures also for a time, though for a much shorter period than its great beauties and applicability would seem to justify. It was not long successfully pursued. It appears to have been too exact in its details, and too comprehensive in its range of elements, whether from the kingdoms of nature, or the realms of art, poetry, and history:—every form which had neither wit nor beauty to recommend it being strictly excluded. Accordingly, already in the sixteenth century, ornamental art fell back to what it was before that time; and we again find the promiscuous mixture of forms of all kinds prevalent, as in the ordinary Renaissance, which, from its far less definite character, gave greater liberty to the tist, in accordance with his own vague notions of

variety, the attainment of which seems now and for a long period to have usurped every other purpose.

18. The Louis Quatorze.—For a century after the development of the Cinque-cento, there was little individuality in the practice of ornamental art; architecture itself was completely domineered over by a mere classical pedantry—rule and measure usurped the place of expression. Towards the close of the seventeenth century, however, a new style commenced to develop itself,—the Louis Quatorze, essentially an ornamental style, and differing very materially in principle from nearly all that preceded it; its chief aim being effect by a brilliant play of light and shade; colour, or mere beauty of form in detail having no part in it whatever. This style, like most others of modern times, arose in Italy, and we may perhaps look upon the Chiesa del Jesu, or Jesus Church, at Rome, as its type or model. The principal decorators of this church were Giacomo della Porta, Pietro da Cortona, and Father Pozzi, author of the well-known 'Jesuit's Perspective.' Of the vague character of the intermediate style after the decline of the Cinque-cento, the various nautilus shells are good examples—something of the Renaissance, Elizabethan, and Louis Quatorze combined.

19. The great medium of the Louis Quatorze was gilt stucco-work, which for a while seems to have almost wholly superseded decorative painting; and this absence of colour in the principal decorations of the period led to its more striking characteristic, infinite play of light and shade. This is accomplished by a constant alternation of round and hollow forms. Consistent with this principle flat details scarcely occur in the Louis Quatorze; flatness being essentially antagonistic to a play of light and shade.

Such being the aim of the style, exact symmetry in the parts was no longer essential, and accordingly in the Louis Quatorze varieties we, for the first time, occasionally find symmetry systematically avoided. This feature was gradually more and more elaborated

till it became essential in the Louis Quinze; and ultimately led to that debased style—the Rococo, in which symmetry, either in the balance of the whole, or in the details of the parts, seems to have been quite out of place. Versailles is the great repertory of the Louis Quatorze, but the whole was evidently intended to present a gorgeous classical scheme of decoration; foreign elements, however, and foreign treatment both found their place, and it is to these foreign features that the decorations owe their individuality. They are the constant and peculiar combination of the scroll and shell—the anthemion treated as a shell, and a small scroll, sometimes plain and sometimes clothed in acanthus foliations; all its other elements are classical, such as we find them treated in the Cinque-cento: the fiddle-shape combination of scrolls is perhaps a legacy of the ordinary Renaissance; and, as a general rule, round or curved surfaces are substituted for flat in all the details of the Louis Quatorze varieties.

20. The Louis Quinze does not differ from the Louis Quatorze in its elements, but yet, from a certain manner of treatment, must be considered as distinct in a discrimination of styles. It differs in this, that the merely characteristic elements of the Louis Quatorze became paramount in the Louis Quinze; all its details, instead of coming direct from the Cinque-cento or Renaissance, came immediately from the French schemes of the preceding reign—the divergence, therefore, from the original types became even wider. The Louis Quinze is accordingly very much less symmetrical than the Louis Quatorze; it is in many of its examples an almost random dispersion of the scroll and shell mixed only with that peculiar crimping of shell-work—the coquillage: it is mere gold and glitter. Still with these aims and elements beautiful effects were produced, when only a slight attention was bestowed upon the arrangement of the masses; but when this last was neglected, the designs became a mere confusion of vagaries, a random dispersal of indescribable forms, and

the Rococo was displayed in the perfection of the Bizarre in ornament; and in this the thread of the historic styles is completely run out. Individuality of detail, and individuality of design, together, were both equally lost: all elements and all schemes were alike, all shapes equally without meaning and without expression; and the art of the ornamentist was necessarily brought to its lowest debasement. Yet this Louis XV., this Rococo, is still the most popular style with our silversmiths.

R. N. WORNUM.

APPENDIX.

BY JAMES GLAISHER.

LIST OF METEOROLOGICAL WORKS OF REFERENCE.

Daniell's Meteorological Essays; Howard's Arrangement and Nomenclature of Clouds; Reid's Law of Storms; Martin on the Rotatory Theory of Storms; Kœmtz, Meteorology, translated by Walker; Drew's Meteorology; Pouillet, Elémens de Physique; Dove's Temperature Tables, British Association Reports 1847; *Glaisher's Hygrometrical Tables; Glaisher's Barometer Tables; Glaisher's Tables of Diurnal Range; Glaisher on Radiation of Heat from the Earth, Philosophical Transactions,* 1847; *Glaisher's Quarterly Meteorological Tables; British Meteorological Society's Reports; Wells' Essay on Dew; Miller's Papers on the Philosophical Transactions on the Fall of Rain in Cumberland; Glaisher's Meteorology of London in relation to the Cholera Epidemic of* 1853–4, *General Board of Health; Annuaire de la Société Météorologique de France; Greenwich Meteorological Observations; Oxford Observations.*

ABLE 1, showing the Monthly Mean Reading of the Barometer, corrected and reduced to the temperature of 32° Fahrenheit, at the Royal Observatory, Greenwich. Height above the level of the sea, 159 feet.

Years.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
1841	29·702	29·697	29·784	29·731	29·731	29·801	29·716	29·768	29·624	29·436	29·672	29·574
1842	29·901	29·876	29·747	29·914	29·782	29·901	29·820	29·869	29·715	29·849	29·599	30·007
1843	29·674	29·473	29·758	29·678	29·664	29·700	29·826	29·819	30·017	29·604	29·718	30·245
1844	29·819	29·498	29.710	30·000	29·945	29·814	29·753	29·677	29·881	29·562	29·690	29·885
1845	29·704	29·840	29·795	29·696	29·712	29·775	29·769	29·729	29·801	29·847	29·575	29·658
1846	29·761	29·849	29·655	29·589	29·779	29·866	29·757	29·777	29·824	29·516	29·821	29·697
1847	29·768	29·782	29·882	29·653	29·764	29·805	29·924	29·876	29·825	29·803	29·905	29·778
1848	29·816	29·517	29·505	29·589	29·926	29·642	29·836	29·732	29·832	29·646	29·785	29·807
1849	29·717	30·106	29·915	29·517	29·766	29·868	29·789	29·841	29·767	29·744	29·743	29·795
1850	29·854	29·828	30·039	29·594	29·714	29·886	29·789	29·787	29·930	29·681	29·728	29·914
1851	29·642	29·891	29·600	29·726	29·891	29·895	29·708	29.890	30·025	29·726	29·781	30·135
1852	29·589	29·857	30·007	29·945	29·786	29·560	29·857	29.649	29·739	29·687	29·465	29·581
1853	29·570	29·525	29·780	29.710	29·754	29·729	29·728	29·793	29·833	29·558	29·941	29·804
1854	29·618	30·041	30·186	29·985	29·667	29·735	29·807	29·889	30·031	29·724	29·728	29·768
1855	29·998	29·593	29·535	29·933	29·697	29·863	29·769	29·874	29·966	29·527	29·864	29·761
Means	29·745	29·758	29·793	29·751	29·771	29·789	29·790	29·798	29·854	29·661	29·734	29·827

The excess or defect of pressure in any month is shown by comparing the number in that month with the numbers in the bottom line, which show the average pressure of the atmosphere in each month, as found from 15 years' observations.

[Glaisher.

TABLE 2, showing the Monthly Mean of the highest Daily Readings of a Thermometer in Air, at the height of 4 feet above the soil at the Royal Observatory, Greenwich.

Years.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.
	°	°	°	°	°	°	°	°	°	°	°	°
1841	39·5	40·7	56·2	56·4	69·7	67·0	67·1	70·6	67·2	55·6	48·7	44·8
1842	36·6	46·6	51·8	54·7	64·5	75·2	71·2	78·1	64·3	53·4	48·1	49·4
1843	44·7	40·2	50·5	57·9	63·3	67·0	71·8	72·5	70·4	55·5	50·0	48.2
1844	43·9	41.6	48·9	63·6	65·9	74·1	72.8	67·9	67·5	56·7	48·1	36·8
1845	43·3	38·4	42·4	57·5	59·6	72·5	71·2	67·7	63·9	59·0	51·8	47·6
1846	48·1	49·0	51·6	56·4	66·7	80·4	77·9	74·4	71·9	58·7	50·3	37·2
1847	40·1	41·5	50·1	55·4	68·0	69·4	78·1	74·4	64·9	61·5	52·7	46·7
1848	38·1	48·7	50·7	56·2	74·4	68·0	73·7	68·9	66·8	59·6	51·1	48·9
1849	45·4	49.4	50·1	52·5	63·8	69·1	74·2	74·2	68·7	59·2	49·8	43·2
1850	38·0	50·7	48·6	58·5	62·1	74·1	72·9	70·6	65·3	54·8	52·4	44·8
1851	48·1	47·4	49·5	54·2	61·4	70·8	71·1	73·4	67·9	59·7	44·3	44·4
1852	47·9	47·5	50·7	58·2	61·8	66·5	80·6	72·6	66·6	55·7	54·5	52·1
1853	47·6	39·1	47·1	54·0	63·1	68·9	70·5	70·9	65·2	59·1	47·8	38·8
1854	44·7	47·2	54·6	61·9	63·7	67·5	73·1	73·1	72·2	59·6	47·7	47·1
1855	39·1	35·7	46·2	57·6	59·9	68·1	73·3	72·9	68·5	59·6	47·7	47·1
Sums	645·1	663·7	749·0	855·0	967·9	1058·6	1099·5	1082·2	1011·3	867·7	745·0	677·1
Means	43·0	44·2	49·9	57·0	64·5	70·6	73·3	72·2	67·4	57·8	49·7	45·1

The numbers in the lowest line show the mean highest daily temperature, as found from these observations, and by comparison with those in the body of the Table: the excess or defect of high daily temperature is immediately seen in every month.

TABLE 3, showing the Monthly Mean of the lowest Readings daily of a Thermometer in Air, at the height of 4 feet above the soil, at the Royal Observatory, Greenwich.

Year.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
	°	°	°	°	°	°	°	°	°	°	°	°	
1841	28·4	31·6	38·7	39·9	48·4	48·2	51·5	54·3	51·2	43·9	38·0	35·4	1841
1842	29·3	36·0	39·2	37·3	45·0	52·2	52·1	56·3	49·8	39·3	39·0	40·2	1842
1843	35·4	31·9	37·5	40·7	45·5	49·0	53·5	55·2	52·3	42·0	38·5	40·3	1843
1844	34·1	30·9	35·7	41·8	45·1	51·6	54·1	50·3	50·2	44·4	39·6	30·6	1844
1845	34·3	27·9	30·8	39·3	42·7	52·2	53·5	50·5	46·9	44·0	40·3	35·8	1845
1846	39·4	39·3	38·1	41·8	47·4	55·1	56·5	56·6	51·4	44·5	40·0	27·9	1846
1847	31·5	30·5	34·3	36·8	47·5	49·7	54·8	52·8	46·1	46·4	40·8	37·2	1847
1848	29·8	38·0	36·4	39·5	43·9	50·5	51·2	50·4	45·9	43·1	35·4	36·2	1848
1849	34·7	36·5	36·3	36·5	46·7	48·5	51·6	54·0	51·2	44·1	38·1	34·1	1849
1850	29·5	39·1	32·1	42·5	43·2	48·1	52·9	52·0	48·2	40·6	41·0	36·1	1850
1851	38·1	34·2	37·4	38·0	41·8	48·7	51·0	53·4	47·3	46·7	32·4	36·4	1851
1852	36·5	35·3	32·1	34·2	43·2	49·4	55·7	54·7	49·2	41·1	44·1	42·4	1852
1853	37·5	29·0	30·9	39·8	41·9	50·2	53·4	51·8	47·2	43·9	36·3	29·5	1853
1854	33·9	33·6	35·4	38·2	42·4	48·3	51·5	52·4	46·5	42·1	35·0	36·1	1854
1855	31·3	24·2	31·9	36·7	40·5	45·7	54·1	53·7	47·7	42·1	35·0	36·1	1855
Sums	53·7	48·0	76·8	133·0	65·2	147·4	47·4	48·4	131·1	48·2	123·5	84·7	Sums
Means	33·6	33·2	35·1	38·9	44·3	49·8	53·2	53·2	48·7	43·2	38·3	35·6	Means

The numbers in the lowest line show the mean lowest daily temperature as formed from this series of observations, and by comparing those in the body of the Table with them, the excesses or defects of low night temperature are immediately seen.

TABLE 4, showing the Mean Daily Range of Temperature in every Month.

Year.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
	°	°	°	°	°	°	°	°	°	°	°	°	
1841	11·1	9·1	17·5	16·5	21·3	18·8	15·6	16·3	16·0	11·7	10·7	9·4	1841
1842	7·3	10·6	12·6	17·4	19·5	23·0	19·1	22·8	14·5	14·1	9·1	9·2	1842
1843	9·3	8·3	13·0	17·2	17·8	18·0	18·3	17·3	18·1	13·5	11·5	7·9	1843
1844	9·8	10·7	13·2	21·8	20·8	22·5	18·7	17·6	17·3	12·3	8·5	6·2	1844
1845	9·0	10·5	11·6	18·2	16·9	20·3	17·7	17·2	17·0	15·0	11·5	11·8	1845
1846	8·7	9·7	13·5	14·6	19·3	25·3	21·4	17·8	20·5	14·2	10·3	9·3	1846
1847	8·6	11·0	15·8	18·6	20·5	19·7	23·3	21·6	18·8	15·1	11·9	9·5	1847
1848	8·3	10·7	14·3	16·7	30·5	17·5	22·5	18·5	20·9	16·5	15·7	12·7	1848
1849	10·7	12·9	13·8	16·0	17·1	20·6	22·6	20·4	17·5	15·1	11·7	9·1	1849
1850	8·5	11·6	16·5	16·0	18·9	26·0	20·0	18·6	17·1	14·2	11·4	8·7	1850
1851	10·0	13·2	12·1	16·2	19·6	22·1	20·1	20·0	20·6	13·0	11·9	8·0	1851
1852	11·4	12·2	18·6	24·0	18·6	17·1	24·9	17·9	17·4	14·6	10·4	9·7	1852
1853	10·1	10·1	16·1	14·2	21·2	18·7	17·1	19·1	18·0	15·2	11·5	9·3	1853
1854	10·8	13·6	19·2	23·7	21·3	19·2	21·6	20·7	25·7	17·5	12·7	11·0	1854
1855	7·8	11·5	14·3	20·9	19·4	22·8	19·2	19·2	20·8	17·5	12·7	11·0	1855
Sums	141·4	163·7	222·1	272·0	302·7	301·6	302·1	285·0	280·2	219·5	171·5	142·8	Sums
Means	9·4	11·0	14·8	18·1	20·2	20·8	20·1	19·0	18·7	14·6	11·4	9·5	Means

The average daily ranges of temperature in each month are shown in the lower line. In like manner the usual range of temperature in each month may be found by taking the difference between the numbers in Tables 3 and 5; and the large ranges which at times take place may be found by taking the difference between the numbers in the same months in the notes following these Tables.

TABLE 5, showing the Monthly Mean Temperature of the Air, at the Royal Observatory, Greenwich.

Year.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean for Year.
	°	°	°	°	°	°	°	°	°	°	°	°	°
1841	33·6	35·3	46·2	47·0	56·8	56·4	57·8	60·5	58·1	48·8	42·7	40·5	48·7
1842	32·9	40·8	44·9	45·2	53·2	62·9	60·2	65·4	56·4	45·4	42·8	45·0	49·6
1843	39·9	36·0	42·9	47·1	52·2	56·3	60·9	62·1	59·5	48·0	43·8	43·9	49·4
1844	39·1	35·2	41·5	51·7	52·9	60·7	61·4	57·7	56·9	49·5	44·0	33·0	48·6
1845	38·3	32·7	35·2	46·3	49·4	60·7	59·8	57·3	53·6	50·2	45·8	41·7	47·6
1846	43·7	43·9	43·3	47·1	54·6	65·3	64·5	63·2	60·1	50·5	46·0	32·9	51·3
1847	35·1	35·4	41·0	45·3	56·4	58·0	65·4	62·1	54·3	52·9	46·9	42·8	49·7
1848	34·6	43·4	43·8	47·6	59·7	58·5	61·5	58·5	55·8	51·6	43·8	44·0	50·2
1849	40·1	43·2	42·5	43·2	54·0	57·9	62·1	62·9	58·8	51·1	44·1	39·1	49·9
1850	33·7	44·7	39·9	48·5	51·3	60·8	62·2	60·2	56·4	47·0	46·5	40·6	49·3
1851	42·9	40·1	42·6	44·7	50·9	58·9	60·1	62·3	56·9	52·6	37·9	40·4	47·5
1852	42·0	40·8	41·3	45·9	51·5	56·1	66·6	62·1	56·8	47·9	48·9	47·6	50·6
1853	42·4	33·3	38·5	45·2	52·0	58·2	60·3	60·0	55·3	50·9	42·1	34·0	47·5
1854	39·0	39·5	43·8	48·4	50·9	55·7	60·3	60·9	58·1	49·4	40·5	41·3	48·8
1855	34·9	29·4	37·9	45·8	48·8	56·9	62·1	62·1	57·1	51·2	41·3	35·6	46·9
Means	38·1	38·2	41·7	46·6	53·0	58·9	61·7	61·2	56·9	49·8	43·8	40·2	48·4

The numbers in the last column show the mean temperature of each year, and those in the lowest line the mean temperature of each month. The defect of temperature in cold months, and of excess in hot months, will be found by comparing the number in the body of the Table with those in the lower line. Cold and hot years will also be similarly indicated.

TABLE 6, containing the Mean Monthly Reading of the Wet-Bulb Thermometer, at the Royal Observatory, Greenwich.

Year.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
	°	°	°	°	°	°	°	°	°	°	°	°	
1841	—	—	44·1	44·2	53·6	52·6	54·5	57·4	55·8	47·1	41·5	38·3	1841
1842	31·9	38·7	42·9	41·9	49·5	57·4	55·9	61·2	54·8	43·9	41·9	44·2	1842
1843	38·8	35·0	41·2	45·0	50·4	53·5	58·2	59·5	56·9	46·4	42·4	43·0	1843
1844	38·7	33·9	40·2	47·6	49·1	55·0	57·3	54·6	54·7	49·3	43·1	32·2	1844
1845	37·4	31·4	33·4	43·5	47·0	57·5	56·7	54·7	51·5	48·4	44·4	40·0	1845
1846	42·5	42·2	41·1	44·8	51·0	59·7	59·8	59·8	57·1	48·8	44·7	31·9	1846
1847	34·5	33·9	37·9	41·4	52·1	53·4	60·0	59·5	51·8	50·9	45·6	41·6	1847
1848	32·6	41·6	41·6	44·5	53·0	54·4	57·6	55·2	53·2	49·3	41·7	42·3	1848
1849	38·6	41·4	39·8	41·5	49·0	48·7	56·2	57·3	54·6	48·2	42·2	37·9	1849
1850	32·5	42·3	37·0	45·4	47·5	54·8	58·4	56·6	52·9	44·4	44·5	39·6	1850
1851	40·9	38·3	40·3	42·2	47·1	54·0	55·7	57·4	52·3	49·5	35·6	38·5	1851
1852	39·2	38·3	38·2	42·3	47·8	52·0	60·7	56·6	52·7	45·0	46·3	44·5	1852
1853	39·8	31·0	35·8	42·0	47·8	52·6	55·8	55·8	52·7	49·4	41·3	33·0	1853
1854	38·0	37·5	40·9	45·0	48·6	52·7	56·2	56·5	53·9	47·1	39·4	39·6	1854
1855	33·8	28·8	36·2	42·6	45·7	52·1	58·2	57·3	53·6	49·4	39·9	33·9	1855
Sums	519·2	514.3	590·6	53·6	739·2	810·4	861·2	99·4	58·5	695·1	604·5	580·5	Sums
Means	37·1	36·7	39·3	43·5	49·3	54·9	57·4	56·6	53·9	46·3	40·3	38·7	Means

TABLE 7, showing the Monthly Temperature of the Dew-Point, at the Royal Observatory, Greenwich.

Year.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
	°	°	°	°	°	°	°	°	°	°	°	°	
1841	–	–	41·7	40·7	50·6	49·1	51·5	54·7	53·7	45·2	40·1	35·5	1841
1842	30·1	36·1	40·5	38·1	45·8	52·8	52·1	57·8	53·3	42·2	40·8	43·1	1842
1843	37·3	33·6	39·0	42·9	48·6	50·8	55·9	57·4	54·4	44·5	40·8	42·0	1843
1844	38·2	33·6	38·6	43·5	45·3	50·2	53·8	51·8	52·7	48·5	41·9	30·6	1844
1845	35·7	29·0	30·7	40·3	44·6	54·7	54·1	52·4	49·5	46·5	42·9	38·1	1845
1846	41·1	40·1	38·6	42·0	47·8	55·2	56·0	57·0	54·5	47·0	43·1	30·1	1846
1847	34·6	31·9	33·9	36·9	48·1	49·2	55·8	57·2	48·0	48·9	44·1	40·1	1847
1848	29·7	39·5	39·0	41·1	47·3	51·7	54·2	52·3	50·8	47·0	39·3	40·2	1848
1849	36·7	39·3	36·5	39·5	44·2	40·3	51·1	52·6	50·9	44·2	39·9	36·3	1849
1850	31·5	39·5	33·5	42·0	43·5	49·6	55·1	53·4	49·7	41·3	42·3	38·3	1850
1851	38·6	36·0	37·6	39·5	43·1	49·8	51·8	53·3	48·1	43·2	32·5	36·7	1851
1852	36·1	35·1	34·4	38·2	44.0	48·3	56·0	51·8	49·0	42·1	43·4	41·1	1852
1853	36·8	26·7	32·3	38·5	43·3	47·5	51·9	52·1	50·2	47·8	40·3	31·1	1853
1854	36·8	34·9	37·4	41·5	46·2	49·7	52·7	52·7	50·1	44·6	38·0	37·5	1854
1855	32·5	25·9	34·0	39·2	42·3	47·7	54·9	53·2	50·2	47·5	38·1	32·4	1855
Sums	495·7	481·2	547·7	603·9	684·7	748·6	806·9	809·7	765·1	680·5	607·5	553·4	Sums
Means	35·4	34·4	36·5	40·2	45·6	49·9	53·8	53·9	51·0	45·4	40·5	36·9	Means

The numbers in the lowest line show the mean temperature of the dew-point in every month, and by comparison with those in the body of the Table, those months are immediately shown in which the amount of water, mixed with the air, in the invisible shape of vapour, was in excess or defect.

TABLE 8, showing the Monthly Mean of the Elastic Force of Vapour, at the Royal Observatory, Greenwich.

Year.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
1841	-	-	0·264	0·271	0·369	0·349	0·381	0·482	0·413	0·302	0·248	0·208
1842	0·168	0·213	0·252	0·230	0·308	0·400	0·389	0·479	0·407	0·269	0·225	0·278
1843	0·223	0·193	0·238	0·276	0·343	0·371	0·447	0·472	0·424	0·294	0·297	0·267
1843	0·231	0·193	0·234	0·283	0·303	0·364	0·415	0·365	0·399	0·342	0·266	0·171
1845	0·209	0·160	0·172	0·250	0·295	0·428	0·419	0·394	0·355	0·317	0·276	0·251
1846	0·258	0·247	0·234	0·269	0·333	0·436	0·449	0·465	0·425	0·323	0·278	0·168
1847	0·200	0·180	0·195	0·219	0·336	0·351	0·446	0·469	0·335	0·346	0·289	0·248
1848	0·165	0·242	0·238	0·248	0·327	0·384	0·421	0·393	0·371	0·323	0·240	0·290
1849	0·218	0·240	0·216	0·242	0·290	0·250	0·375	0·397	0·373	0·290	0·246	0·214
1850	0·117	0·242	0·192	0·267	0·283	0·356	0·434	0·409	0·357	0·260	0·269	0·231
1851	0·234	0·212	0·225	0·242	0·278	0·358	0·385	0·407	0·336	0·279	0·184	0·218
1852	0·213	0·204	0·199	0·231	0·288	0·339	0·449	0·385	0·348	0·268	0·281	0·258
1853	0·218	0·145	0·183	0·233	0·280	0·329	0·386	0·389	0·391	0·333	0·250	0·174
1854	0·218	0·203	0·224	0·262	0·313	0·357	0·399	0·399	0·389	0·295	0·229	0·225
1855	0·184	0·140	0·196	0·234	0·270	0·331	0·431	0·406	0·391	0·329	0·230	0·184
Sums	·56	·14	·262	3·757	4·616	5·403	6·224	6·313	5·734	4·570	908	3·395
Means	0·204	0·201	0·218	0·258	0·308	0·360	0·415	0·421	0·395	0·300	0·260	0·226

The numbers in this Table show the length of a column of mercury, balanced by the water mixed with the air; and if taken from those in the Table showing the mean pressures of the atmosphere, the difference will show the lengths of the column of mercury supported by air only.

TABLE 9, showing the Weight of Vapour in a Cubic Foot of Air, at the Royal Observatory, Greenwich.

Year.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	
1841	–	–	3·1	2·9	4·1	3·9	4·3	4·8	4·6	3·4	2·9	2·4	1841
1842	1·9	2·5	2·9	2·9	3·5	4·4	4·4	5·3	4·5	2·8	2·9	3·1	1842
1843	2·6	2·2	2·8	3·2	3·8	4·2	5·0	5·3	4·8	3·4	2·9	3·1	1843
1844	2·7	2·1	2·7	3·2	3·3	4·1	4·6	4·3	4·4	3·9	3·0	2·2	1844
1845	2·5	1·9	2·0	2·9	3·4	4·9	4·6	4·4	4·0	3·6	3·1	2·7	1845
1846	3·0	2·9	2·7	3·0	3·5	4·8	4·9	5·1	4·7	3·7	3·2	1·9	1846
1847	2·3	2·1	2·3	2·6	3·8	3·9	5·1	5·2	4·0	3·9	3·3	2·8	1847
1848	1·9	2·8	2·8	3·0	3·7	4·2	4·7	4·4	4·2	3·6	2·8	2·8	1848
1849	2·5	2·7	2·5	2·8	3·3	2·8	4·1	4·4	4·2	3·4	2·8	2·5	1849
1850	2·0	2·8	2·2	3·1	3·2	3·9	4·8	4·6	4·1	3·0	3·1	2·7	1850
1851	2·7	2·4	2·6	2·8	3·2	4·0	4·3	4·5	3·8	3·6	2·2	2·5	1851
1852	2·4	2·4	2·3	2·7	3·2	3·8	5·0	4·3	3·9	3·0	3·2	3·0	1852
1853	2·5	1·7	2·1	2·7	3·2	3·7	4·3	4·3	4·1	3·7	2·9	2·3	1853
1854	2·4	2·4	2·6	3·0	3·6	4·0	4·4	4·5	4·0	3·4	2·7	2·6	1854
1855	2·1	1·8	2·3	2·8	3·1	3·7	4·8	4·5	4·1	3·7	2·7	2·1	1855
Sums	33:5	32·7	37·9	43·6	6·9	60·3	9·3	9·9	3·4	7·1	13·7	8·7	Sums
Means	2·4	2·3	2·7	3.1	3·5	4·0	4·6	4·7	4·2	3·5	2·9	2·6	Means

TABLE 10, showing the Degree of Humidity of the Atmosphere, at the Royal Observatory, Greenwich.

Year.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1841	-	-	85	80	80	77	88	82	85	88	90	83	1841
1842	90	84	84	76	76	70	76	79	89	89	93	93	1842
1843	91	91	87	86	88	82	84	85	85	88	91	93	1843
1844	96	88	90	74	76	68	76	81	86	96	92	92	1844
1845	93	86	83	80	84	82	82	84	86	88	90	88	1845
1846	91	87	83	83	77	70	74	80	82	88	90	90	1846
1847	96	89	76	73	73	73	71	86	83	87	91	91	1847
1848	82	86	83	79	65	76	78	80	84	85	84	86	1848
1849	88	86	80	87	69	53	68	69	75	81	85	90	1849
1850	89	83	78	79	76	67	78	78	78	82	86	92	1850
1851	85	85	83	82	75	70	74	73	72	80	82	87	1851
1852	79	81	79	75	76	75	70	70	75	81	82	80	1852
1853	81	76	76	77	73	68	74	75	82	90	93	89	1853
1854	92	84	78	77	85	82	76	75	75	83	91	86	1854
1855	95	99	86	78	79	71	78	73	78	88	85	84	1855
Sums	1248	1205	1231	136	102	1184	97	120	15	94	125	124	Sums
Means	89	86	82	79	77	79	76	78	81	86	88	88	Means

TABLE 11, showing the Weight of a Cubic Foot of Air, at the Royal Observatory, Greenwich.

Year.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.
	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.	Grs.
1841	–	–	545·2	543·5	532·3	534·3	531·8	529·1	529·0	535·9	547·0	545·9
1842	562·7	553·3	546·1	549·1	537·5	528·9	531·4	525·3	532·4	547·3	543·5	550·6
1843	550·2	550·8	547·4	542·2	536·2	532·9	529·1	527·9	534·4	539·7	546·8	556·1
1844	553·9	553·4	549·2	543·2	540·8	529·7	527·7	530·3	534·8	537·0	545·8	562·4
1845	553·1	562·0	558·3	543·7	540·7	528·9	529·6	531·8	537·1	541·7	541·8	547·9
1846	548·4	549·1	546·3	540·6	535·7	523·9	524·6	526·1	530·2	535·3	546·0	558·9
1847	557·9	557·5	553·3	544·1	533·6	532·6	526·4	528·9	536·8	537·9	546·7	548·9
1848	559·3	543·6	543·0	540·1	533·1	529·0	529·1	530·4	535·1	536·6	548·2	548·1
1849	551·0	554·5	552·1	543·8	536·4	534·5	527·9	527·9	530·9	538·9	546·8	553·6
1850	563·1	547·8	557·3	540·3	538·3	531·1	527·4	529·7	536·5	542·5	543·9	552·0
1851	546·5	553·3	546·1	546·0	542·1	533·1	528·4	529·4	537·5	536·1	543·8	557·3
1852	546·3	552·9	555·1	548·8	539·6	530·3	524·2	525·4	532·7	541·6	536·4	540·0
1853	545·8	555·6	549·6	545·2	540·3	531·3	523·1	530·1	535·8	535·5	552·6	559·4
1854	549·7	557·7	555·7	547·6	537·7	533·7	525·4	530·7	536·5	540·4	550·7	551·6
1855	562·0	561·1	550·2	548·2	541·9	534·9	526·6	529·2	536·2	534·7	552·4	557·2
Sums	749·9	7742·6	8254·9	8186·4	8066·2	7969·1	7912.7	7932·2	8015·9	8081·1	8192·4	8289·9
Means	556·0	553·8	550·3	545·7	537·7	531·2	527·4	528·8	534·4	538·7	546·1	552·6

The numbers in the lowest line show the average weight of a cubic foot of air in every month.

In my Hygrometrical Tables, all the hygrometric results, when the readings of the dry and wet bulb thermometers are whole degrees, are given by inspection, and when the readings are affected by parts of a degree, the results are obtained with very little trouble.

[Glaisher.

TABLE 12, showing the Monthly Fall of Rain, at the Royal Observatory, Greenwich.

Year.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	
1841	2·1	1·3	1·4	1·9	2·1	2·7	3·6	2·3	3·9	5·9	3·7	2·4	1841
1842	1·0	1·1	1·9	0·4	2·1	0·9	3·0	1·8	4·0	1·4	4·2	0·7	1842
1843	1·4	2·4	0·5	1·7	2·8	1·3	2·4	3·6	0·5	4·2	2·3	0·4	1843
1844	2·4	2·3	2·9	0·4	0·4	1·8	2·8	2·0	1·2	4·0	4·3	0·4	1844
1845	2·4	0·9	1·5	0·6	2·2	1·9	1·9	3·1	2·1	1·4	2·4	2·0	1845
1846	2·8	1·5	0·9	3·1	1·5	0·5	1·5	4·0	1·8	5·1	1·5	1·1	1846
1847	1·4	1·4	0·8	1·0	1·4	1·5	0·7	1·9	1·6	2·0	2·0	2·0	1847
1848	1·2	2·6	3·1	3·4	0·4	3·5	2·0	4·3	2·4	3·5	1·2	2·6	1848
1849	1·6	2·2	0·5	2·2	3·9	0·2	2·9	0·5	3·2	2·7	1·5	3·4	1849
1850	1·2	1·3	0·3	2·3	2·4	0·9	2·9	1·9	1·3	1·4	2·5	1·3	1850
1851	2·7	1·2	4·1	2·3	0·8	1·3	2·8	1·5	0·8	1·8	0·6	0·6	1851
1852	3·6	0·9	0·2	0·5	1·9	4·6	2·3	4·4	3·8	3·0	6·0	2·2	1852
1853	2·0	0·9	1·5	3·1	1·6	2·8	6·0	2·2	2·4	4·3	1·5	0·7	1853
1854	1·7	1·0	0·4	0·6	3·3	1·0	1·7	2·9	0·7	2·6	1·4	1·4	1854
1855	1·0	1·4	1·5	0·1	1·8	0·7	5·1	1·1	5·4	2·6	1·4	1·4	1855
Sums	28·5	22·4	21·5	23·6	28·6	25·6	41·6	37·5	35·1	45·9	36·5	22·6	Sums
Means	1·9	1·5	1·4	1·6	1·9	1·7	2·7	2·5	2·3	3·0	2·4	1·5	Means

TABLE 13, showing the Mean Monthly Results for Meteorological Elements, at the Royal Observatory, Greenwich, in the Year 1855.

1855. Month.	Mean Reading of the Barometer.	TEMPERATURE OF THE AIR.							Mean Temperature of Dew-point.	Mean Elastic Force of Vapour.	Mean Weight of Vapour in a Cubic Foot of Air.	Mean Additional Weight of Vapour required to saturate a Cubic Foot of Air.	Mean Degree of Humidity, complete saturation = 100.	Mean Weight of a Cubic Foot of Air.	WIND.			Mean Amount of Cloud.	RAIN.	
		Highest.	Lowest.	Range in the Month.	Mean, of all the Highest.	Mean, of all the Lowest.	Mean Daily Range.	Mean.							Prevailing Direction.	Mean Daily Pressure in lbs. on Square Foot.	Mean Daily Horizontal Movement of Wind.		Number of Days it fell.	Amount Collected on the Ground in Inches.
	In.	°	°	°	°	°	°	°	°	Grs.	Grs.	Grs.		Grs.		Lbs.	Miles.			
January .	29·998	52·4	16·2	36·2	39·1	31·3	7·8	34·8	31·7	·200	2·4	0·3	91	538	N.E. & S.W.	0·22	47	8·7	20	1·5
February .	29·593	48·4	11·1	37·3	35·7	24·2	11·5	29·1	26·7	·165	2·9	0·2	91	557	E. & N.E.	0·18	64	7·6	11	1·0
March . .	29·535	57·8	24·5	33·3	46·2	31·9	14·3	37·6	33·6	·212	2·5	0·4	86	546	N.E. & S.E.	0·25	64	7·8	12	2·0
April . .	29·933	72·8	25·9	46·9	57·6	36·7	20·9	45·9	38·8	·251	2·9	0·8	78	544	S.W. & N.E.	0·24	96	5·8	4	0·1
May . . .	29·679	81·5	28·3	53·2	59·9	40·5	19·4	49·0	42·3	·284	3·3	0·8	80	536	N.E. & S.	0·21	118	7·7	12	1·8
June. . . .	29·863	83·5	39·3	44·2	68·5	45·7	22·8	56·0	47·8	·348	3·9	1·5	74	530	S.W. & N.E.	0·01	87	6·4	9	0·9
July . . .	29·769	79·0	43·7	35·3	71·3	54·2	17·1	62·2	55·5	·444	5·0	1·3	80	532	S.W.	0·03	67	7·0	10	3·3
August. .	29·674	77·9	40·3	37·6	72·9	53·7	19·2	62·4	53·9	·433	4·7	1·5	86	535	S.W.	0·05	107	5·9	10	1·4
September	29·906	78·2	34·1	44·1	68·5	47·7	20·8	57·2	50·5	·378	4·3	1·1	80	532	N.E. & S.W.	0·04	75	5·4	22	5·2
October .	29·527	66·8	35·0	31·8	58·7	45·2	13·5	51·2	47·8	·346	4·0	1·5	89	531	S.W. & N.W.	0·29	106	7·6	17	1·3
November	29·864	58·0	25·7	32·3	46·5	36·8	9·7	41·3	38·5	·250	2·9	0·3	92	548	N.E.	0·04	63	8·1	17	1·1
December	29·761	52·4	16·9	35·5	40·2	30·9	9·3	35·6	31·3	·178	2·1	0·6	79	551	S.W. & N.W.	0·21	114	6·9	11	1·1
Means	29·780	67·5	29·0	38·5	55·6	39·9	15·7	47·1	42·6	·290	5·7	0·8	83	540				7·1	Sum 144	Sum 23·8

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